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FLIGHT TEST EVALUATION OF SLANT VISUAL RANGE/APPROACH LIGHT CONTACT HEIGHT (SVR/ALCH) MEASUREMENT SYSTEM

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16. Abstract

The Slant Visual Range/Approach Light Contact Height (SVR/ALCH) System reports the slant visual range that can be seen when the pilot is at 100 feet above ground level and the approach light contact height, which is the altitude at which a pilot will see five light bars, as a landing is conducted under Category II conditions.

To provide SVR/ALCH information, the system utilizes a 100-foot tower equipped with forward scatter and luminance meters, an illuminance meter, a touchdown transmissometer, and a minicomputer to process the data. The system was installed at the National Aviation Facilities Experimental Center (NAFEC) and data collected during the period from the fall of 1974 through January 1976.

The main objective of this program phase (Phase III) was to evaluate the SVR/ALCH system in terms of accuracy of the SVR and ALCH algorithms compared to what a pilot actually sees during an approach. From the limited data obtained to date, there is evidence that the algorithms predict SVR and ALCH values which agree reasonably well with what the pilot sees.

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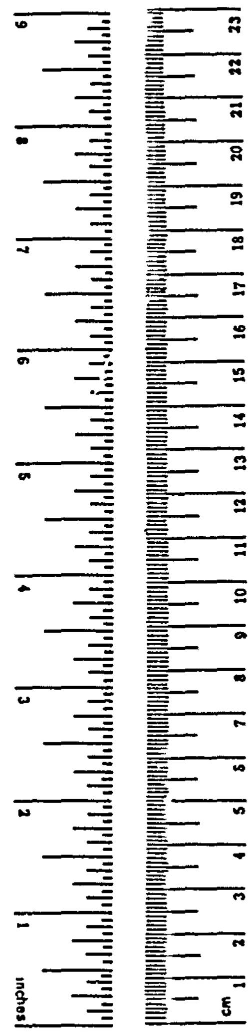
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

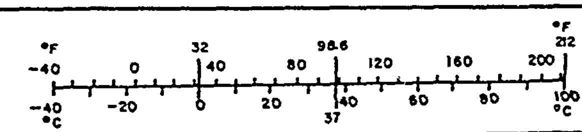
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The following NWSC Crane personnel have contributed significantly to the SVR/ALCH program:

G. Bradley
M. Brown
R. Brown
R. Chipman
C. Lohkamp
D. Montgomery
R. Williams

A note of appreciation is given to all the NAFEC personnel who participated in the flight test effort. A special note of appreciation is given to E. Schlatter and W. Smith for their effort in coordinating the flight tests and assisting in the maintenance of the instrumentation.

The USAF Systems Command and, in particular, the Flight Dynamics Laboratory, Terminal Area Control Branch, WPAFB, was also helpful in making available an aircraft for flight tests. Unfortunately, not enough fogs were encountered to warrant their participation.

The cooperation and guidance of Messrs. A. Hilsenrod and A. Larsson of the FAA Aviation Weather Systems Branch, Systems Research and Development Service, has been greatly appreciated.

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ABSTRACT

The Slant Visual Range/Approach Light Contact Height (SVR/ALCH) system predicts the slant visual range that can be seen when the pilot is at 100 feet above runway level as he conducts a landing under Category II conditions. It also predicts the approach light contact height, which is the altitude at which the pilot will see a minimum of five light bars on approaching in low visibility conditions.

To provide SVR/ALCH information, the system utilizes a 100-foot tower equipped with forward scatter and luminance meters, an illuminance meter, a touchdown transmissometer, and a minicomputer to process the data. The system was installed at the National Aviation Facilities Experimental Center (NAFEC) and the tests were initiated in the fall of 1974. This report presents the analysis of a portion of data collected during the period from the fall of 1974 through January 1976.

One objective of this program phase (Phase III) is to evaluate the SVR/ALCH system in terms of accuracy of the SVR and ALCH algorithms compared to what a pilot actually sees during an approach. From the limited data obtained to date, there is evidence that the algorithms predict SVR and ALCH values which agree reasonably well with what the pilot sees. Differences between system predicted values and pilot reported values are not unexpected considering the psychophysical factors of the pilots and the errors present in the measurements of the atmospheric and luminance parameters. A case in point is the 24 February flight test. The predicted SVR and ALCH values tended to be larger than the reported values for one observer and the reverse trend true for another observer. A primarily Category I snowfog of 20 January 1975 showed the greatest difference between SVR/ALCH predicted and reported values. Inspection of this data showed horizontal heterogeneity which could be the factor causing the discrepancy.

The results of tests completed on the ALCH/SVR system indicates that the system can yield meaningful data and that the system can be highly reliable.

1. INTRODUCTION

The work described in this report was performed by the Applied Sciences Department, Naval Weapons Support Center, Crane, Indiana. The work was performed for the Federal Aviation Administration. This report described the third phase of a three-phase program to design and implement a Slant Visual Range/Approach Light Contact Height (SVR/ALCH) measurement system.

At present, Phase III testing is essentially complete but more tsesting is contemplated in the future.

The following terms are defined to aid in understanding the results presented.

Under daylight conditions, SVR is defined as the greater of the slant distance to (1) the farthest high intensity runway edge light or approach light which a pilot can see when at an altitude of 100 feet on the approach path, or (2) the slant path distance which would have a transmittance of 5.5%.

Under daylight conditions, SVR is defined as the greater of the slant distance to (1) the farthest high intensity runway edge light or approach light which a pilot can see when at an altitude of 100 feet on the approach path, or (2) the slant path distance which would have a transmittance of 5.5%.

Under conditions of darkness, SVR is defined as the slant distance to the farthest high intensity runway edge light or approach light which a pilot will see when at an altitude of

100 feet on the approach path.

ALCH is the height on the glide path at which a pilot will see, and should continue to see, a minimum of five bars of approach lights at 100-foot spacings if extended to touchdown, assuming a standard cockpit cut-off angle of 15 degrees.

Phase I of the program consisted of analytical comparison of possible SVR/ALCH candidate systems (FAA-RD-72-42). Phase II consisted primarily of gathering transmittance data with the proposed SVR/ALCH system and a series of tower mounted transmissometers. The transmissometers represented the true environment while the SVR/ALCH system was compared to them. Results of Phase II were very encouraging. A detailed description can be found in FAA Report No. FAA-RD-74-7; however, Figure 1 of this Phase III report is included to illustrate the favorable results previously obtained.

The third phase of the program was composed of the testing and evaluation of the SVR/ALCH system under flight test conditions. The testing site was the NAFEC Airport, Atlantic City, New Jersey. A Gulfstream aircraft was used to make landing approaches during Category II and III visibility conditions, permitting comparisons to be made between pilot reported visibility and SVR/ALCH system visibility. This phase also included a test of the reliability of the SVR/ALCH equipment in an on-site environment. The equipment considered in terms of reliability were the forward scatter meters, luminance meters, illuminance meter, and minicomputer system. A discussion of the problems encountered will be given in Sections 4 and 7.

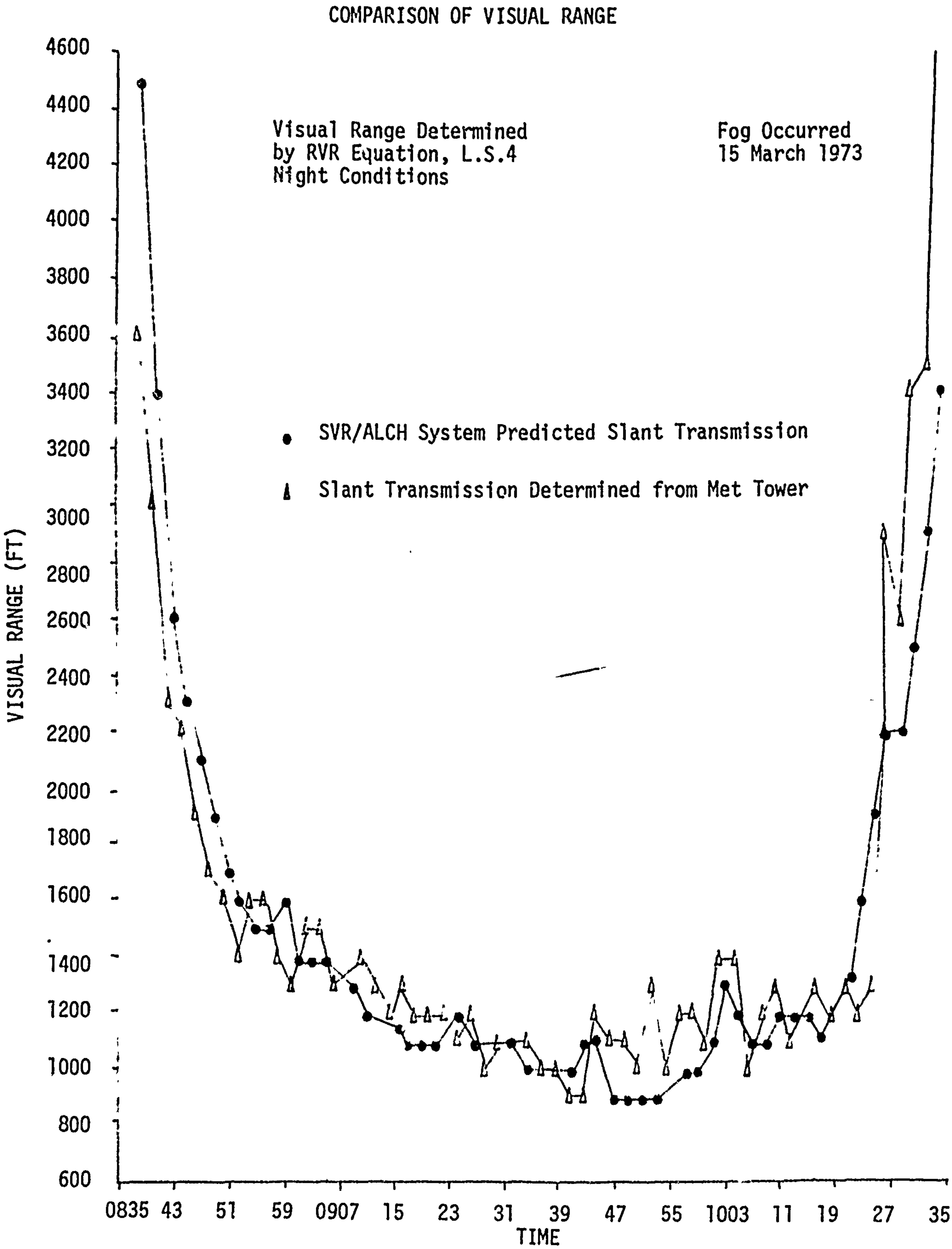

COMPARISON OF VISUAL RANGE
Visual Range Determined
by RVR Equation, L.S.4
Night Conditions
Fog Occurred
15 March 1973
SVR/ALCH System Predicted Slant Transmission
Slant Transmission Determined from Met Tower
VISUAL RANGE (FT)
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0835 43 51 59 0907 15 23 31 39 47 55 1003 11 19 27 35
TIME

FIGURE 1

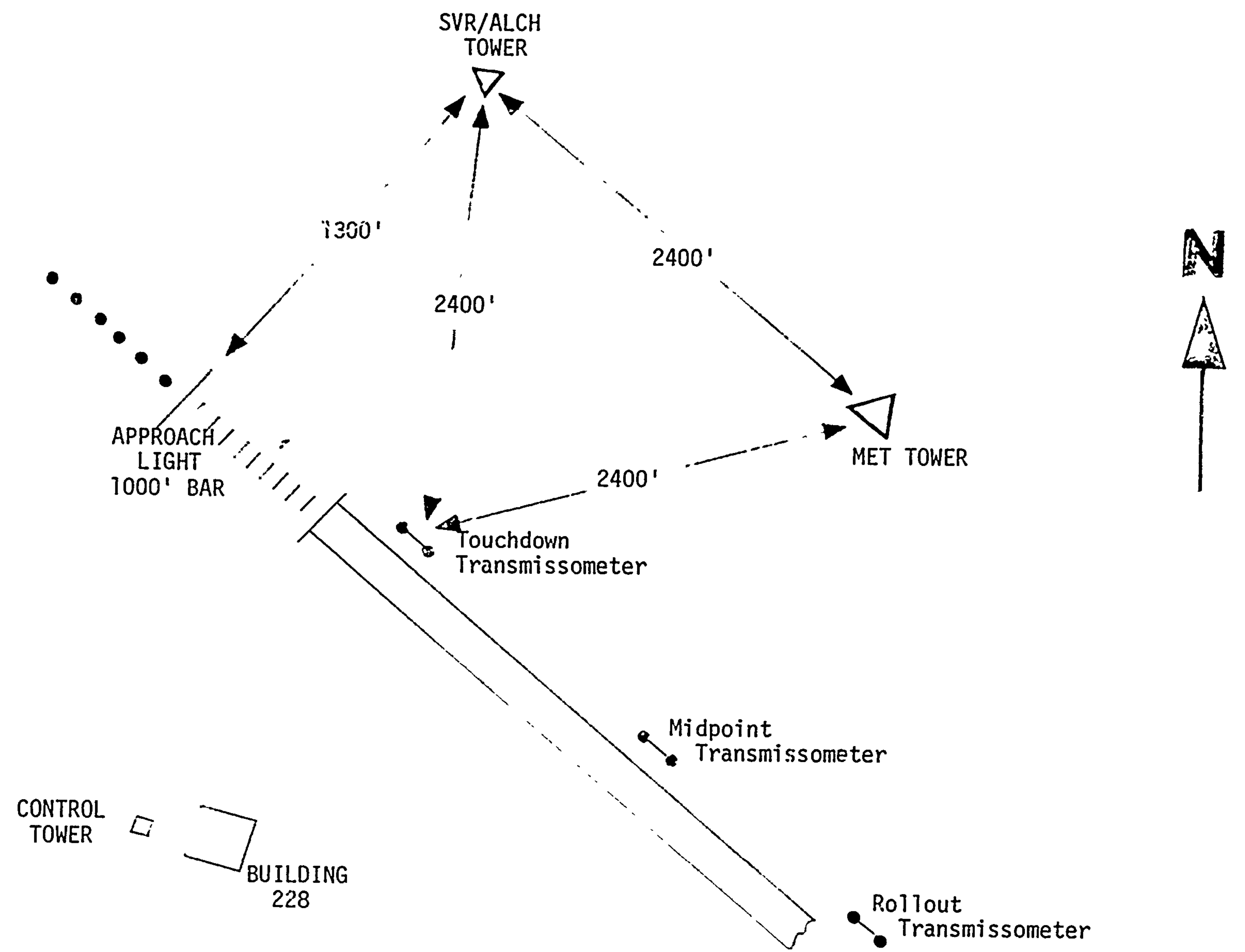
2. EXPERIMENTAL FACILITY

The experimental components consist of the SVR/ALCH tower and instrumentation, touchdown (TDT), midpoint (MPT) and rollout transmissometers (ROT), meteorological (met) tower instrumentation, extended area instrumentation radar system (EAIRS), and NAFEC Building 228 (see Figure 2). The EAIRS system and met tower are both self-contained in that neither is connected with the minicomputer in Building 228. Figure 3 shows the minicomputer system.

2.1 Description of SVR/ALCH Measurement System

The SVR/ALCH tower is located perpendicular to runway 13 at a distance of 1,300 feet from the 1,000-foot approach light bar. The aircraft altitude, when on the glide slope, is 100 feet above the 1,000-foot bar as it descends on the glide path. The SVR/ALCH is 100 feet high. It is located within the safety envelope as defined by FAA regulations. The SVR/ALCH tower has forward scatter meters (FSM's) mounted at 10 and 100 feet AGL. The FSM's measure the extinction coefficients at their respective altitudes. To aid in the maintenance of the FSM's, the electronic package was separated from the optics and placed at the bottom of the tower. Figure 4 shows the SVR/ALCH tower.

Luminance meters are mounted on the tower at 50 and 100 feet. Their function is to determine the luminance level that the pilot is adapted to, which is used in the SVR/ALCH predictions. Both meters are pointing parallel to runway 13 at a depression angle of 5°. The luminance meters' directions of look correspond to the direction of look of the aircraft pilot. An illumination meter is located 100 feet south of the SVR tower at a height of four feet. Its function is to measure daytime illumination which is used in the ALCH calculation. The measured incident illumination is used to determine the top of the fog level using a technique which relies on determining the illumination difference with



NAFEC SVR TOWER PLACEMENT

FIGURE 2

DATA REDUCTION SYSTEM

FIGURE 3

SVR/ALCH TOWER SYSTEM

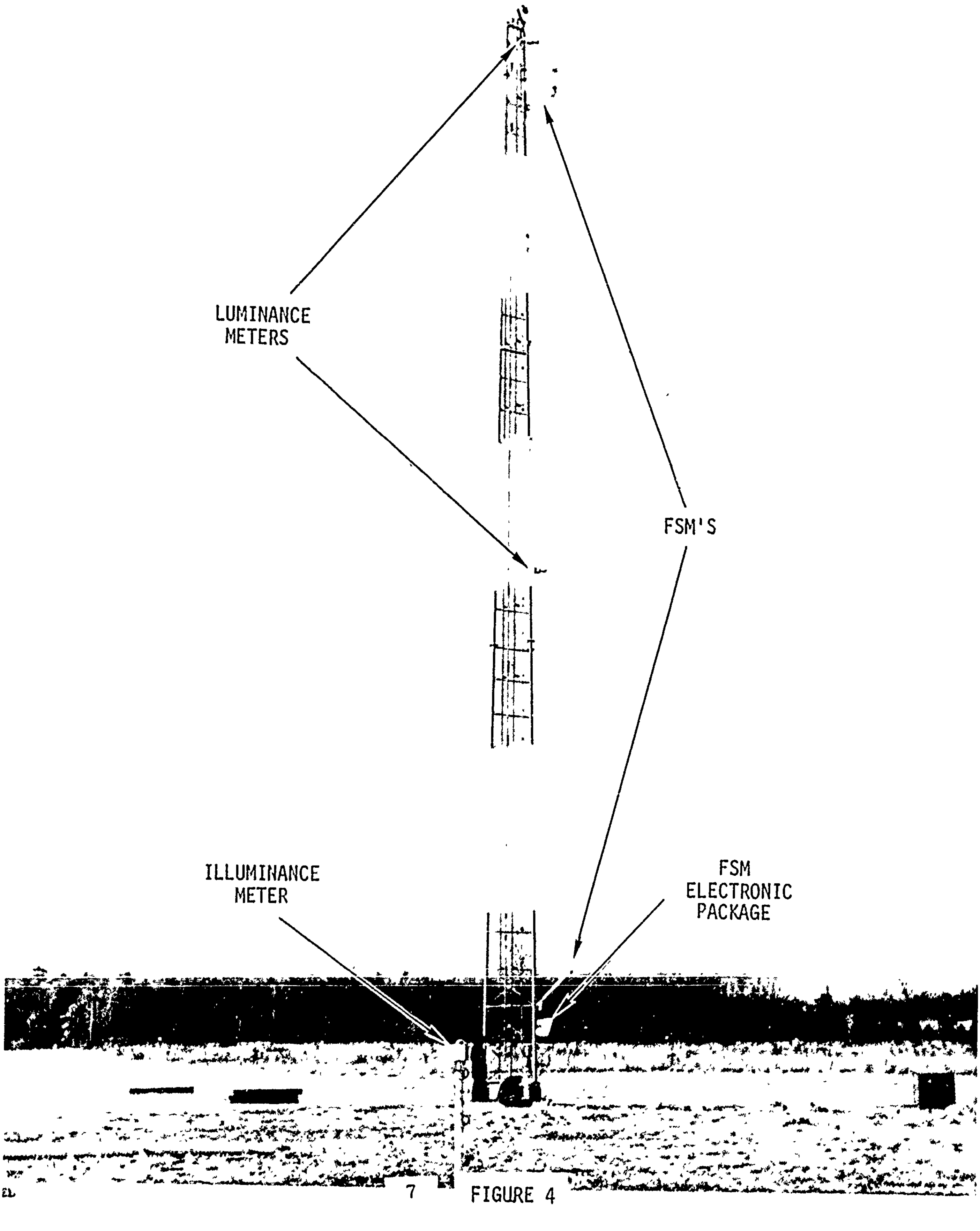


FIGURE 4

and without fog present. The extinction coefficient derived from FSM readings coupled with the flux loss allows calculations of the thickness of the fog layer. The illumination meter's position relative to the SVR/ALCH tower ensures that a shadow from the tower is not cast on it.

The transmissometers located at touchdown, midpoint and rollout are standard NBS 250' baseline transmissometers and are used in the RVR calculations.

Both SVR/ALCH tower instrumentation and transmissometers are connected to the minicomputer in Building 228. The minicomputer is a NOVA 1220 with a memory of 8,000 sixteen-bit words. This computer reduces the data gathered and computes SVR and ALCH. The raw data, SVR and ALCH is then recorded in digital form on teletype and magnetic tapes.

A met tower system is used to provide a supplementary check of the homogeneity of fog during SVR/ALCH tests. It consists of two towers with transmissometer sources mounted at 5, 15, 51, 97, 123 and 154 feet on one tower and the receivers mounted at the same heights on the more rigid met tower. A more detailed description of this facility can be found in FAA Report No. FAA-RD-74-7.

3. DETERMINATION OF SVR/ALCH

SVR is derived from readings from the FSM's, touchdown transmissometer, approach and runway light settings, and the luminance meter positioned 100 feet above ground level on the tower. These measurements are then used in conjunction with psychophysical illuminance threshold data to predict SVR. As previously defined, SVR refers to the range at which runway lights or approach lights can be detected or the slant path distance which would have a transmittance of 5.5%. The runway lights are referenced if SVR $\geq$ 900 feet; the approach lights are used if SVR $<$ 900 feet.

The ALCH calculations are based on readings from approach light settings, FSM's, the 50- and 100-foot luminance meters and the illuminance meter positioned near the ground. These readings are then used in conjunction with psychophysical data to predict ALCH.

A detailed description of the calculations can be found in Appendix A. The luminance calculations required knowledge of the optical depth associated with the fog. A method utilizing sun position is described in Appendices B and C.

To emphasize the importance of fog density and adaptation luminance on SVR calculation, the following paper analyses were performed. SVR values were calculated for a range of hypothetical luminance values maintaining the atmospheric transmission constant. Table I presents these results. As seen from Table 1, an 800-foot SVR difference exists from the upper to lower assumed luminance limits. Tables 2 and 3 contain the results of varying atmospheric conditions and keeping the luminance levels fixed at 256 and 3,000 footlamberts respectively. The analyses demonstrate that large SVR differences can be observed by varying either the atmospheric transmission or the adaptation luminance.

TABLE 1

EFFECT OF LUMINANCE

Approach Light Setting = 5
Edge Light Setting = 5
FSM10 = 25.0%
FSM100 = 25.0%

LUMINANCE (Ft-L)	SVR (Ft)
5	1900
15.0	1800
67.0	1600
287.0	1500
1243.0	1300
3000.0	1100

TABLE 2

EFFECT OF TRANSMISSION

Approach Light Setting = 5

Edge Light Setting = 5

Luminance = 256 Ft-Lamberts

% TRANSMISSION OVER 250-FOOT BASELINE	SVR (Ft)
2.0	700
5.0	900
16.0	1210
22.0	1400
30.0	1700
36.0	1930
41.0	2130
46.0	2420
50.0	2640
55.0	2970
60.0	3350
65.0	3820
70.0	4400
75.0	5160
80.0	6270
85.0	7900

TABLE 3

EFFECT OF TRANSMISSION

Approach Light Setting = 5
Edge Light Setting = 5
Luminance = 3,000 Ft-Lamberts

% TRANSMISSION OVER 250-FOOT BASELINE	SVR (Ft)
2.0	600
5.0	700
16.0	940
22.0	1100
30.0	1328
36.0	1500
41.0	1670
46.0	1840
50.0	1990
55.0	2240
60.0	2510
65.0	2840
70.0	3240
75.0	3750
80.0	4430
85.0	5490

4. TEST PROCEDURES

Flight test participants included Messrs. Smith and Schlatter, Extended Area Instrumentation Radar System personnel and aircraft pilots and observers. These pilots and observers who participated in the tests were Messrs. Johnson, Bazer, Terry, Ryan, Laprecht, Bailey, Tranter, and Budoff. Building 228 personnel, W. Smith and E. Schlatter, were responsible for test coordination. Before the flight tests began, aircraft personnel who were to be involved in the test were given test procedure instructions.

The aircraft personnel were instructed that the primary events to be recorded were SVR and ALCH as defined in Section 1. The copilot was to serve as the visual observer in recording and reporting ALCH and SVR and maintained direct radio contact with NAFEC personnel in Building 228. All of the copilot's comments were recorded on magnetic tape in Building 228. To verify the ALCH prediction of when five lights were visible, the copilot was to call out "five lights" over the radio at the moment five approach lights were seen and depress an event marker button in the aircraft. The Building 228 personnel recorded the time of the event and the comment made. The event mark would also appear on a flight recorder on board the aircraft. When the aircraft was at an altitude of 100 feet, the copilot would push the event button and relay the number of runway edge lights that could be seen to Building 228. Included on the aircraft was a camera which monitored the pilot's view of the approach. As the event marker was depressed, a light was flashed in the periphery of the camera field of view providing a very subjective tool in analyzing what visual cues the pilot required before giving an event mark.

During the time the approaches were made, the data from the forward scatter meters, luminance meters, illuminance meter, and the touchdown transmissometer were utilized by the minicomputer in Building 228 to calculate SVR/ALCH. The calculated values of SVR and ALCH were output on the teletype unit. Before reported and predicted values could be compared, however, the absolute time the events occurred had to be obtained from the flight recorder. However, due to a time synchronization problem, only the time between events could be obtained. Therefore, the absolute time of events was obtained from Building 228 and aircraft communications. After finding the absolute event times, the aircraft range and altitude were obtained from the EAIR system. The reported ALCH was read directly from the EAIR system, and the reported SVR was obtained from the number of runway edge lights that the copilot observed. The predicted SVR and ALCH was then compared to the reported values.

4.1 Problem Areas that Affected Data Acquisition

Many problems arose during the tests which limited the amount of data obtained and made coordination extremely difficult. During the test period, the aircraft was in for maintenance for a two-week period and thus was unavailable. At other times, the test aircraft was not available due to involvement in higher priority programs. On one occasion, the DME on board the aircraft was not functioning, and on another occasion, the approach lights were not operating.

One of the most perplexing problems was predicting the time and date that a fog was to occur. The test schedule was arranged so that an alert had to be issued at 1600 hours on the day that a fog was expected to occur, putting Building 228 personnel, EAIR system personnel, and aircraft personnel in a ready state throughout the night and into the next day. If a fog did occur, test participants were to man their respective stations. As might be expected, fog forecasting was a very difficult task. Some fogs were missed because an alert had not been issued. At the other extreme, a number of very light fogs were flown against that were not acceptable for system checkout. Some of the fogs which occurred had duration periods of only one to two hours. Therefore, by the time personnel were notified and assembled, the fog had dissipated. These logistics problems account for the paucity of test results.

5. TEST RESULTS

A total of nine flight tests were actually flown against the SVR/ALCH system. Five of the nine are presented in this report. The other four tests were conducted in fogs that were too thin or light to actually obtain any useful data that related to SVR and ALCH values. Of the five flight tests presented, primarily the flights of 20 January, 25 September, and 24 February 1975 actually fall into the Category II classification, the classification for which the system was primarily designed. The tests of 31 January and 18 February were performed in very thin fogs which would fall in the upper Category I and above classifications. The following gives a description and results of the presented fogs in order of occurrence.

Flight Test of 20 January 1975

The flight test began at 1251 and lasted until 1530. A total of 13 approaches was made on runway 13. Restricted visibility was attributed to a combination of fog and snow. The snow, however, seemed to be the dominant factor.

Figure 5 shows a plot of time versus transmission for two met tower transmissometers and the FSM's on the SVR tower. As can be seen, the 100-foot FSM differs from the 87-foot transmissometer quite significantly. The 15-foot transmissometer deviates from 10-foot FSM by about 20 percentage points from 1430 to 1600 hours. This figure demonstrates the heterogeneity that exists in the snow-fog between the met tower and the SVR tower, which are separated by a distance of 2,400 feet. Some deviations can also be seen between the SVR tower and touch-down transmissometer (TDT) which are separated by a distance of 2,500 feet (see Figure 6).

TRANSMISSION COMPARISON

FOG OCCURRED 1/20/75

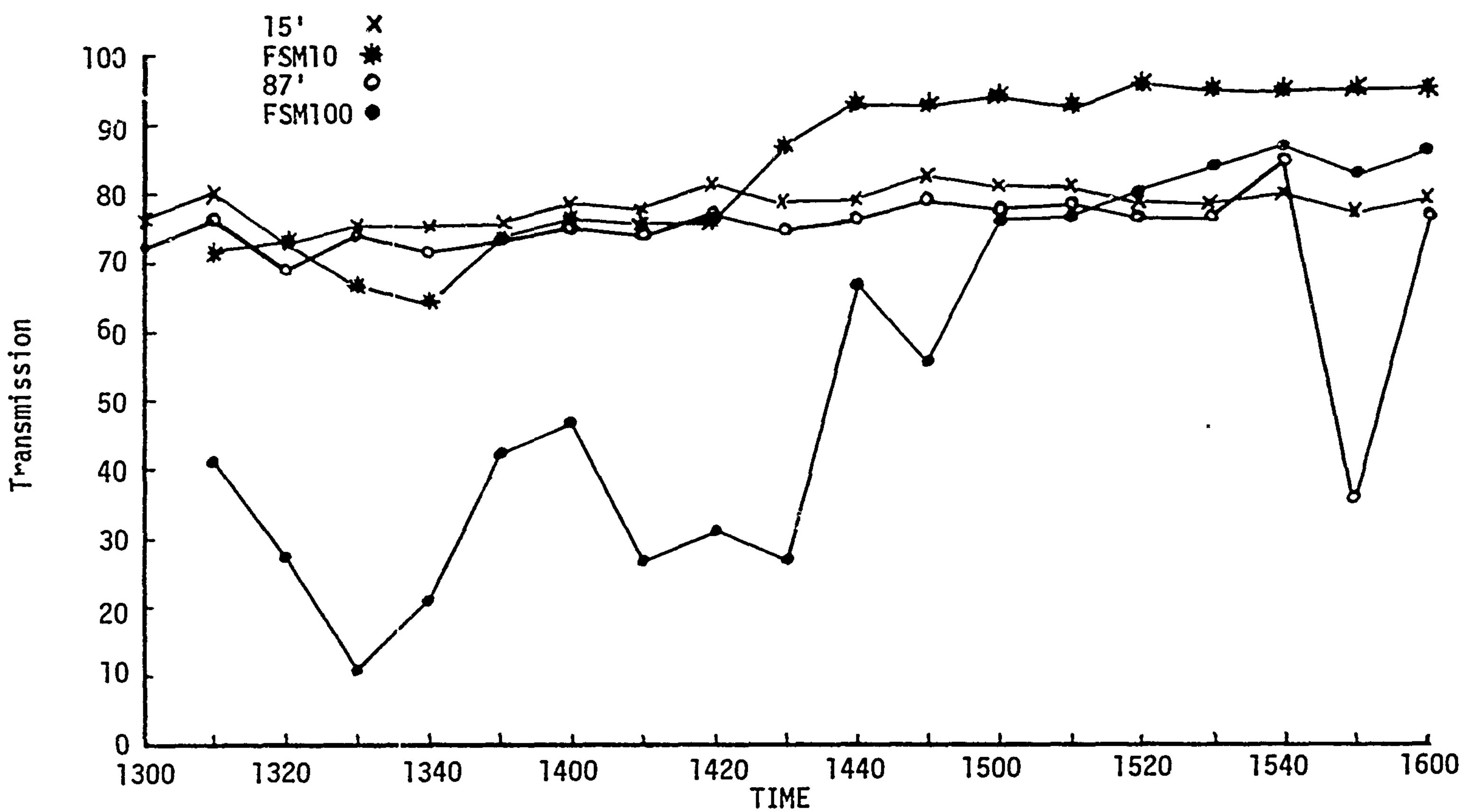


FIGURE 5

TRANSMISSION COMPARISON

FOG OF 20 JANUARY 1975

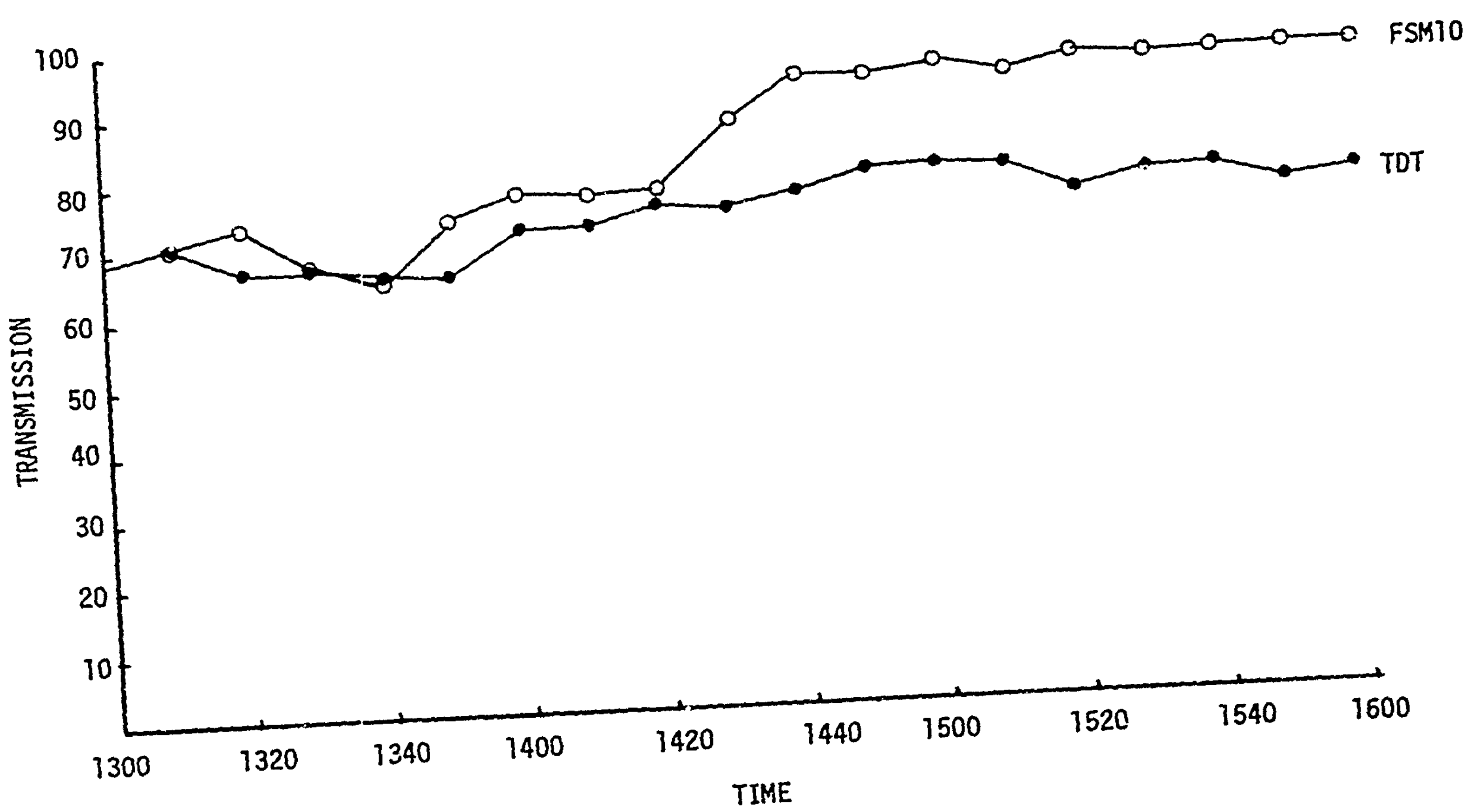


FIGURE 6

The first five approaches were of little use in comparing system ALCH and SVR to the pilots' reported values. The first two approaches were learning experiences with no confident event marks being obtained and all event marks occurring simultaneously. During approaches 3, 4, and 5, the approach lights were not operating. However, limited data was obtained on approaches 6-13 and is presented in Table 4 which shows the reported versus predicted SVR and ALCH values. Approaches 6-13 occurred at times 1358, 1410, 1425, 1437, 1452, 1505, 1517, and 1529 respectively. When examining the data in Table 4, one must keep in mind that the visual conditions were in most cases representative of Categories I and not Category II.

TABLE 4

FLIGHT TEST - 20 JANUARY 1975

(Snow - Fog)

APPROACH NO.	PREDICTED SVR	REPORTED SVR	PREDICTED ALCH	REPORTED ALCH
6	1960	1000+ *	200	Not Reported
7	1500	1000+	200	380
8	1600	4600	200	450
9	2500	**	300	470
10	2600	6300	200	450
11	3300	6100	200	520
12	5100	4400	400***	450
13	4300	4400	400***	480

* Pilot's response was "threshold plus" but didn't define "plus".

**Pilot was flying below glide slope.

***400 feet is the largest allowed predicted value of ALCH.

The predicted and reported SVR values obviously do not agree well for approach 8, 10 and 11. This might be attributed to a denser fog or snow near the 100-foot level of the SVR tower and a lesser density at this altitude near the runway. Figure 5 indicates a layer at the

100-foot level of the SVR tower while a relatively clear condition exists near the met tower near the 100-foot level. Unfortunately, no measurement exists at the 100-foot level at the runway approach zone. On the other hand, approaches 12 and 13 show better agreement than the previous approaches. This can probably be attributed to fog dissipation at the SVR tower as seen in Figure 5.

The ALCH values likewise do not agree well for approaches 6-11 while approaches 12 and 13 agree fairly well. Again, the above argument can be used to explain such results. At this point, it should be noted that no measurements exist above 100 feet. Therefore, any predictions of ALCH above 100 feet can only be based on the measurements of the FSM's at 10 and 100 feet extrapolated to altitudes above 100 feet.

It is worthwhile noting some of the pilot's comments in reporting SVR and ALCH. As described in Section 4, it is from the pilot's comments that the reported SVR is calculated. Many of the SVR comments included descriptive phrases such as 1/2 or 1/3 the runway. It turns out that at these visual ranges, it is almost impossible to give an exact number of runway edge lights that can be seen. It is for this reason that the SVR reported values are plus or minus 500 feet.

Flight Test of 31 January 1975

The flight test began at 0900 and lasted until 1115 hours. Ten approaches were made on runway 13. However, the fog failed to materialize with the transmissometers reading values in the 80-90% range. Therefore, only three of the ten runs were studied and it was questionable if these should have been analyzed.

Figure 7 shows a plot of FSM10, FSM100 and TDT as a function of time. As can be seen, very little difference exists within the fog.

TRANSMISSION COMPARISON

FOG OF 31 JANUARY 1975

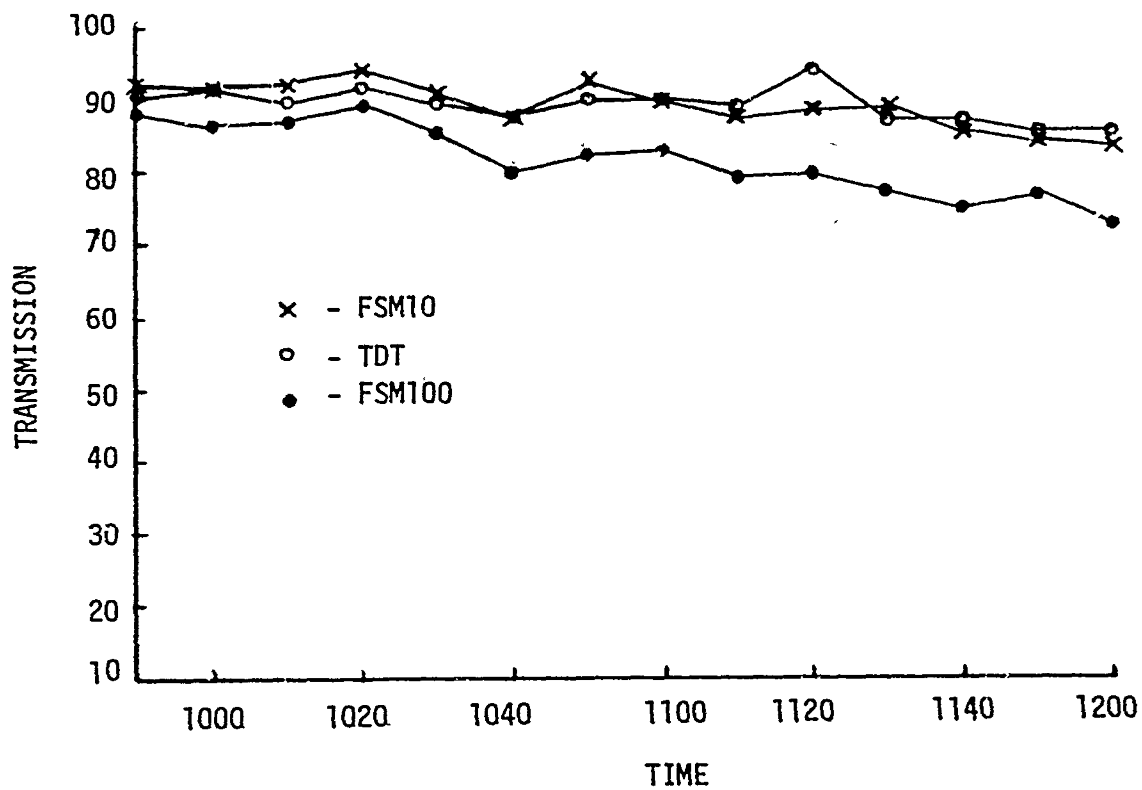


FIGURE 7

Because of the small amount of fog encountered, only a few comparisons between predicted and reported ALCH values could be made and are shown in Table 5. The agreement obtained for ALCH values is fairly good; however, SVR comparisons aren't given because at the 100-foot altitude, the copilot could see the complete runway.

TABLE 5

FLIGHT TEST - 31 JANUARY 1975

APPROACH NO.	ALCH PREDICTED	ALCH REPORTED
6	400	320
7	400	330
8	400	340

Flight Test of 18 February 1975

The flight test began at 0930 and ended at 1030 hours. Five approaches were made to runway 13. Not unlike the two previous flights, this flight also was not suitable for system checkout.

The surface visibility was reported as one mile plus. The fog was more like a low stratus cloud. In most of the approaches, breakout was obtained at altitudes of 150-200 feet; therefore, SVR comparisons were not made. Figure 8 shows the transmission at three positions on the met tower and three data points for the FSM10 and FSM100. As can be seen, the fog becomes denser with altitude but is apparently horizontally heterogeneous since the FSM's did not turn on at the same time as the met tower transmissometers.

Flight Test of 24 February 1975

The flight test began at 0800 and ended at 1100 hours. Seventeen approaches were made to runway 13. The fog was advective, denser at the top than at the bottom. The RVR values ranged from 700 to 3,000 feet, putting the visual range primarily in the Category II and III classifications.

TRANSMISSION COMPARISON

FOG OF 18 FEBRUARY 1975

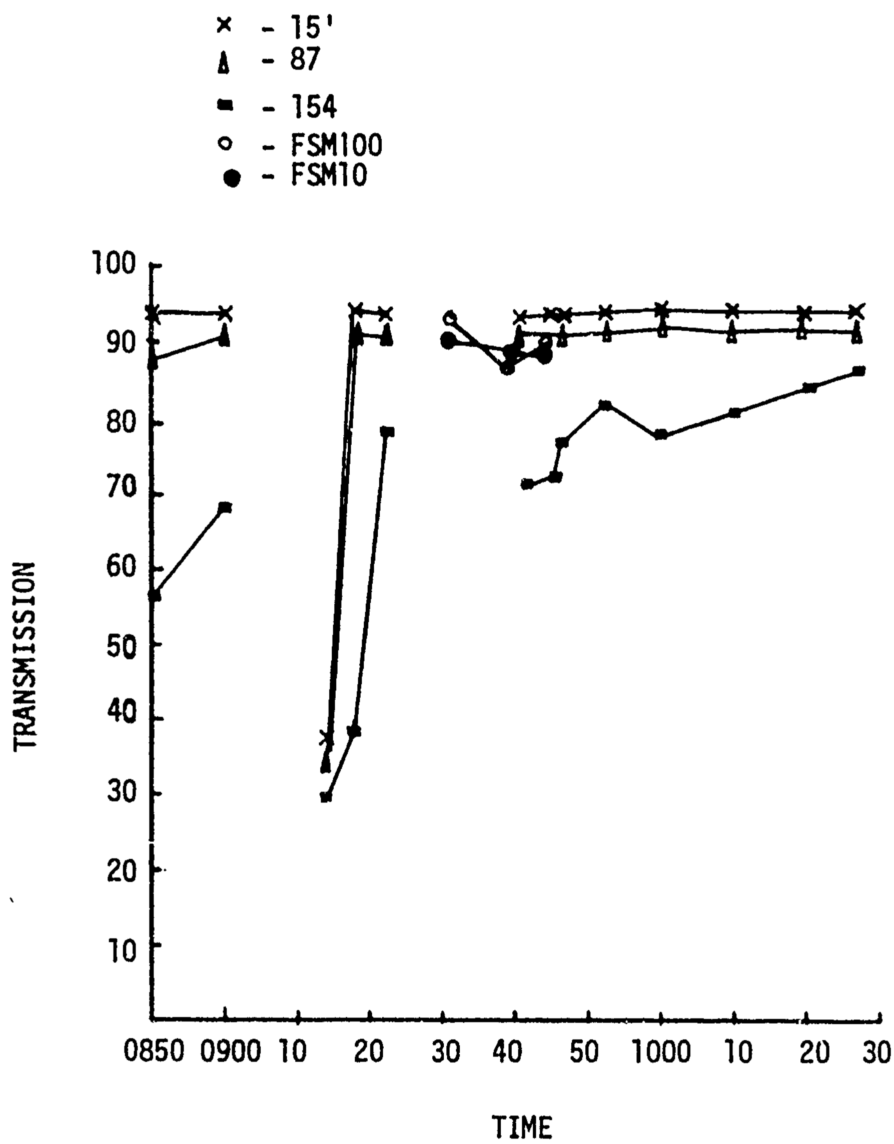


FIGURE 8

Figure 9 gives a plot of the FSM's and two transmissometers on the met tower. It is interesting to note how well the 15-foot transmissometer and FSM10 as well as the 87-foot transmissometer and FSM100 agree with each other. This demonstrates the homogeneity that seems to exist with horizontal displacement of the measuring devices. Figure 10 also shows the homogeneity in that the TDT and FSM10 are reading approximately the same with respect to time. From the fogs that have been examined, this phenomenon seems to hold true for Category II fogs and to deviate from this pattern as the fog dissipates. Similar results can be found in the Phase II report of this study. This fog was primarily a Category II classification, and as such its density corresponded more closely to that for which the system was designed than the three previous fogs.

Table 6 shows the comparisons of reported and predicted SVR and ALCH values. SVR values for approaches 3-9 show signs of agreement. However, some of the predicted values are 200 to 300 feet larger than the reported values. Approaches 10-17 show the reverse trend with the reported values 400 to 500 feet higher than the predicted SVR values. Upon inspection of the data, the only factor that changed for the latter half of the approaches was the person doing the reporting. Therefore, the differences were attributed to observer-to-observer variation. One possible explanation for the discrepancies is the difference between observers in the degree of certainty needed to mark an event.

The average difference between the predicted and reported values of SVR was 523 feet; however, eliminating approaches 2 and 17 from the SVR analysis reduces the average difference between predicted and reported SVR to 380 feet. Elimination of these two approaches is justified in that both of these approaches occurred during rapidly changing fog density periods. Figure 10 illustrates the transmission of the touchdown transmissometer during the time the approaches were made. Approach 2 occurred at 0818 and approach 17 occurred at 1056. Approaches 2-9

TRANSMISSION COMPARISON

FOG OF 24 FEBRUARY 1975

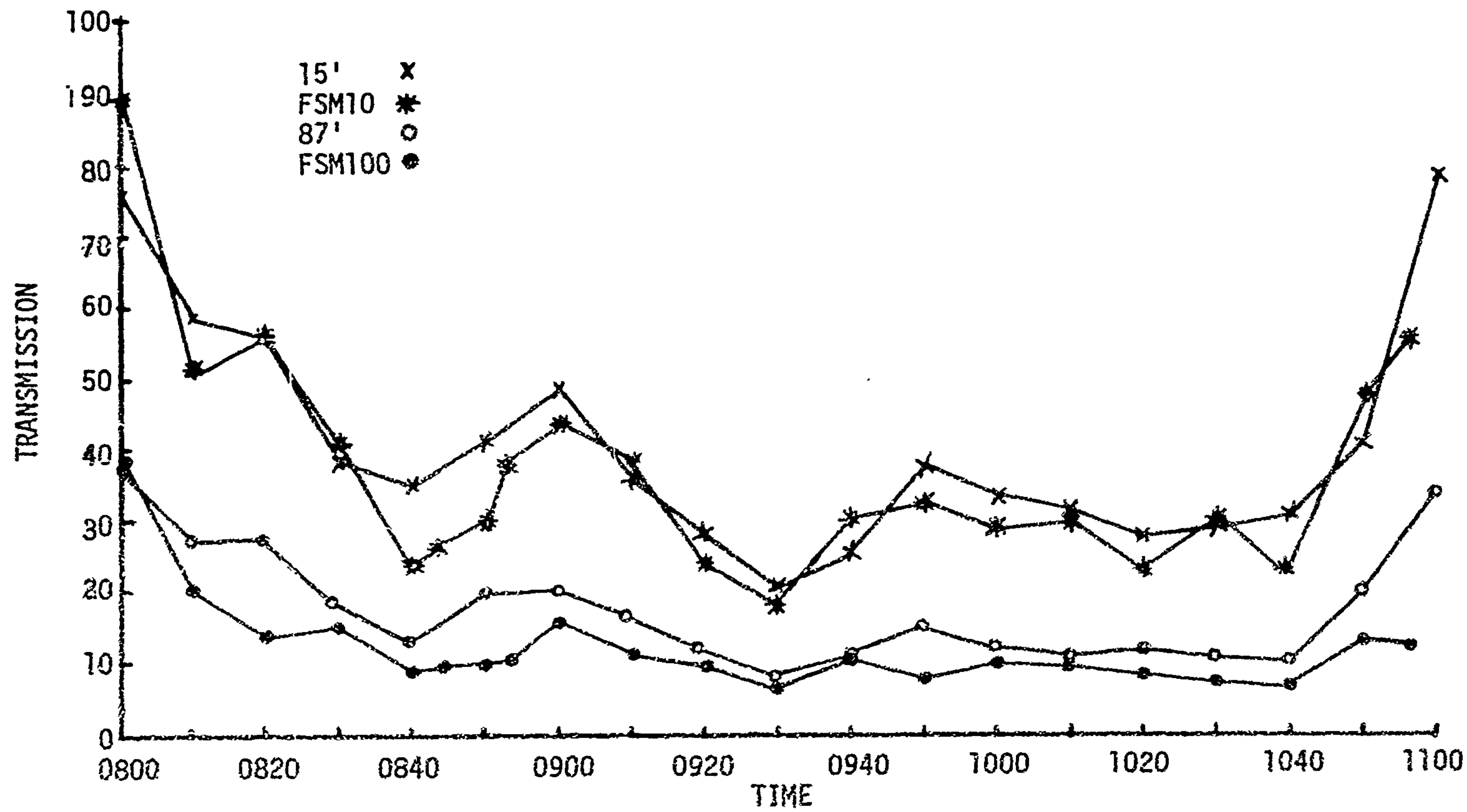


FIGURE 9

TRANSMISSION COMPARISON

FOG OF 24 FEBRUARY 1975

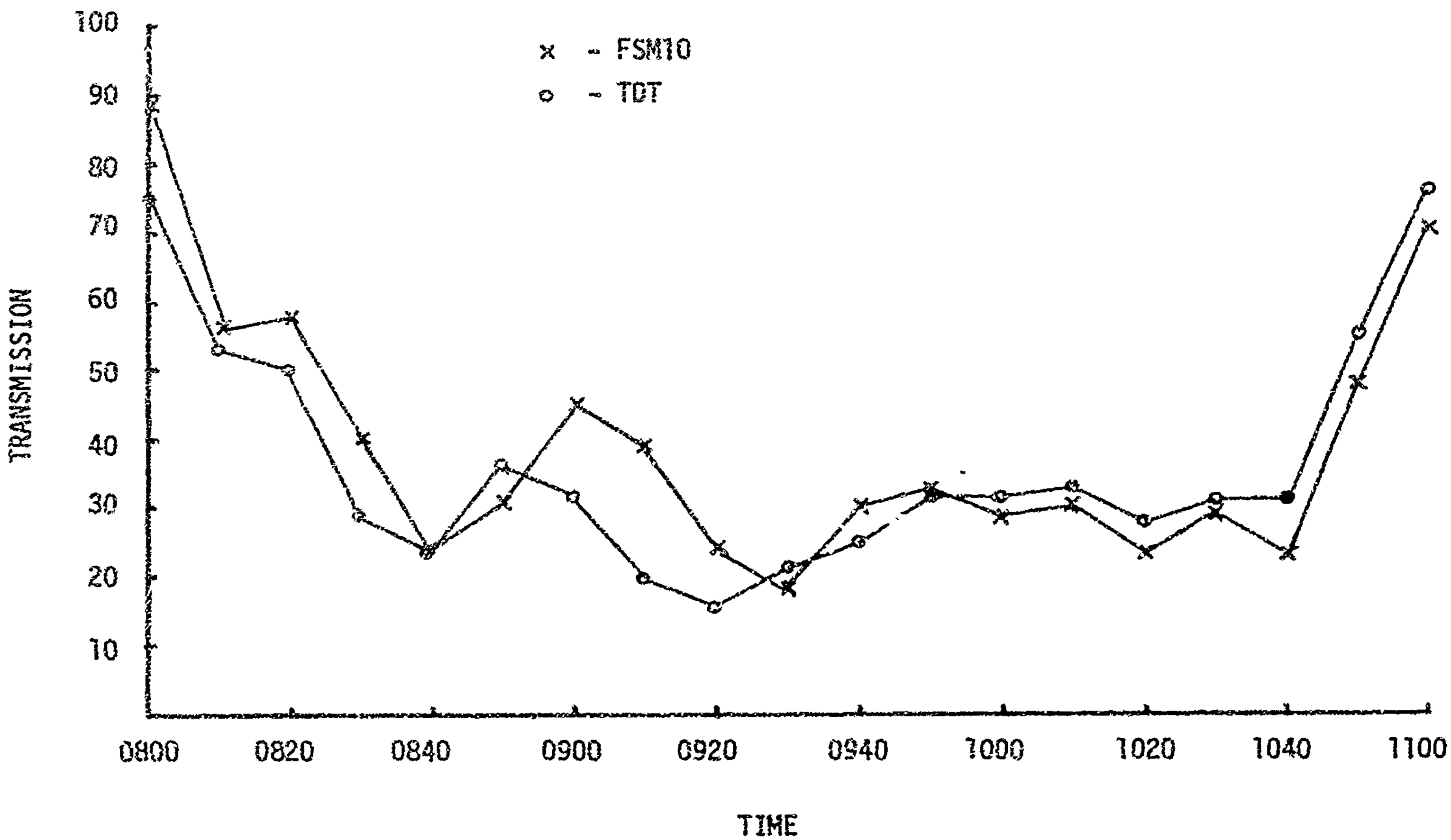


FIGURE 10

show predicted ALCH values greater than or equal to reported values; approaches 10-17 show reported values greater than predicted values. This is similar to the trend which occurred with the SVR and lends further support to the observer to observer variance theory. The average difference between the predicted ALCH and the pilot reported ALCH for the 24 February test was 35 feet.

Although differences do exist between reported and predicted values for the above data, one should not become overly alarmed. Any experiment which involves a human observer is going to exhibit a certain amount of observer variance. Keeping this in mind and realizing the inherent errors associated with reporting SVR, the discrepancies do not seem nearly as severe.

TABLE 6

FLIGHT TEST - 24 FEBRUARY 1975

APPROACH	SVR		ALCH	
	PREDICTED	REPORTED	PREDICTED	REPORTED
1	1800	Not reported	200	Not reported
2	1300	650	200	170
3	1300	1100	200	160
4	1100	1100	150	160
5	1300	1000	150	Not reported
6	1300	Not reported		Not reported
7	2100	2100	150	60
8	1000	Event not recorded	150	100
9	1000	800	100	100
10	1100	1400		No event marks recorded
11	1100	Not reported	150	148
12	1100	1500	150	160
13	1000	1800	100	170
14	1000	1700	150	160
15	1000	1600	100	190
16	1019	1400	100	Not reported
17	1325	3300	150	170

Flight Test of 25 September

The flight test began at 1000 and lasted until 1130. In the afternoon, the testing resumed at 1500 and continued until 1740. A total of 22 approaches yielding data were completed. Although the fog lasted a great length of time, the fog did not provide consistant visibilities below 2400 feet RVR as would have been preferred. The RVR values ranged from 7,687 feet to 1,700 feet with only five approaches in Category II conditions. The fog density was greater at the 100-foot level than at the 10-foot level. Figure 11 shows this fog structure. A similar fog density structure was observed at the met tower indicating horizontal homogenity. Examination of the test approaches having RVR between 2,400 feet and 1,200 feet shows that the average difference between system predicted SVR and pilot reported SVR was 312 feet. ALCH values predicted were extermely close to values reported by the pilot. The average reported ALCH value, for the fogs in Category II, differed from the predicted values by an average of ten feet. Table 7 gives the complete data obtained on the test.

FOG VERTICAL STRUCTURE
Fog of 25 September 1975

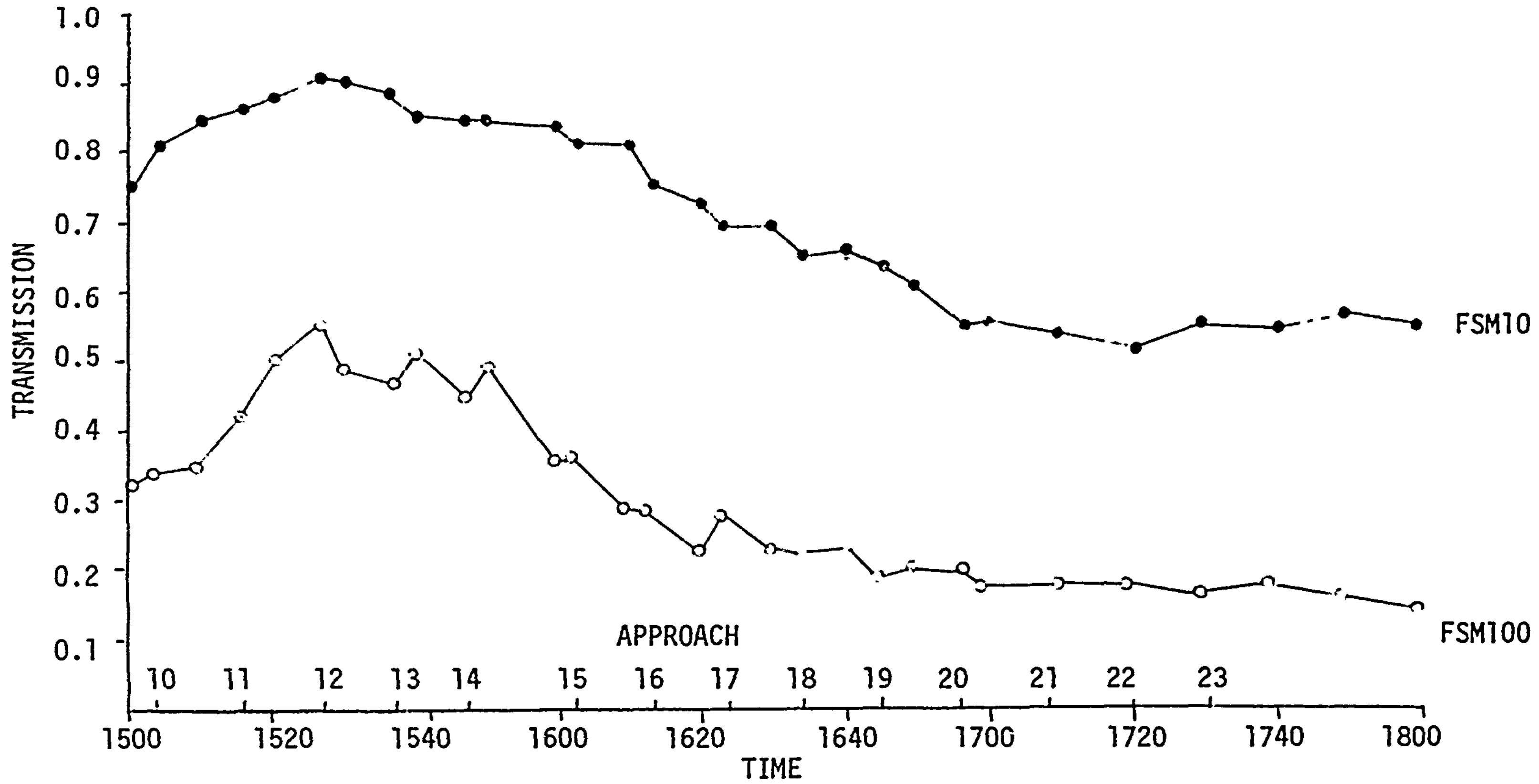


FIGURE 11

TABLE 7

FLIGHT TEST - 25 SEPTEMBER 1975

APPROACH	RVR	SVR PREDICTED	SVR REPORTED	ALCH PREDICTED	ALCH REPORTED
1	3653	1400	Not Reported	150	160
2	3891	1700	1400	200	160
3	3891	2300	900	200	Not Reported
4	3362	2000	1000	200	170
5		COMMUNICATION BREAKDOWN			
6	4075	2400	6500	200	190
7	4429	3600	10700	300	220
8	6954	5000	3500	400	210
9	7684	6900	Not Reported	400	270
10	3500	2900	3800	200	160
11	5934	3500	4000	300	240
12	5671	4700	4200	300	250
13	4245	3800	3100	300	240
14	4560	3800	2400	300	270
15	3849	3100	2500	300	270
16	2918	2700	1800	200	220
17	2730	2500	2500	200	220
18	2658	2200	2600	200	200
19	1988	2000	2100	200	210
20	1803	2000	2000	200	200
21	1796	2000	1300	200	200
22	1717	2000	1800	200	200
23	1700	2200	1400	200	230

6. COMPARISON OF SVR SYSTEM WITH RVR SYSTEM

The SVR system may at some future date be used to complement the present runway visual range (RVR) system. In order to realize this complementary role, it must be remembered that RVR is visibility on a horizontal path along the runway and is not intended to infer information about the slant visibility. SVR is visibility along the slant path from a position over the tenth approach light bar and infers nothing about visibility along the runway.

There are differences in the computing algorithms as well as differences where the sensors are located. Algorithm differences are (1) RVR illuminance thresholds (E_t) are fixed at two and 1,000 milecandles for night and day cases respectively, and SVR illuminance thresholds are computed as a function of adaptation level for the day case and taken as the constant, two milecandles, for the night case; (2) the SVR algorithm uses the approach lights as the viewing source for SVR less than 900 feet, while the RVR algorithm uses the runway edge lights as the viewing source. A complete SVR description can be found in Appendix A.

To demonstrate the differences in values of slant visual range and runway visual range in fog, several graphs were prepared. The differences in values between SVR and RVR results from (1) vertical and horizontal heterogeneity in the fog and (2) differences in the algorithms. Figures 12 through 15 are included to demonstrate that truly there are differences in slant visual and runway visual range.

After reviewing the data presented, it seems apparent that conditions can exist such that significantly different SVR and RVR values are obtained. Based on the preliminary results obtained in this phase and the results obtained in Phase II, the RVR system can be complemented with the SVR/ALCH system by providing visual information as viewed from 100 to 400 feet above ground level.

VISUAL RANGE COMPARISON

FOG OF 25 JANUARY 1975

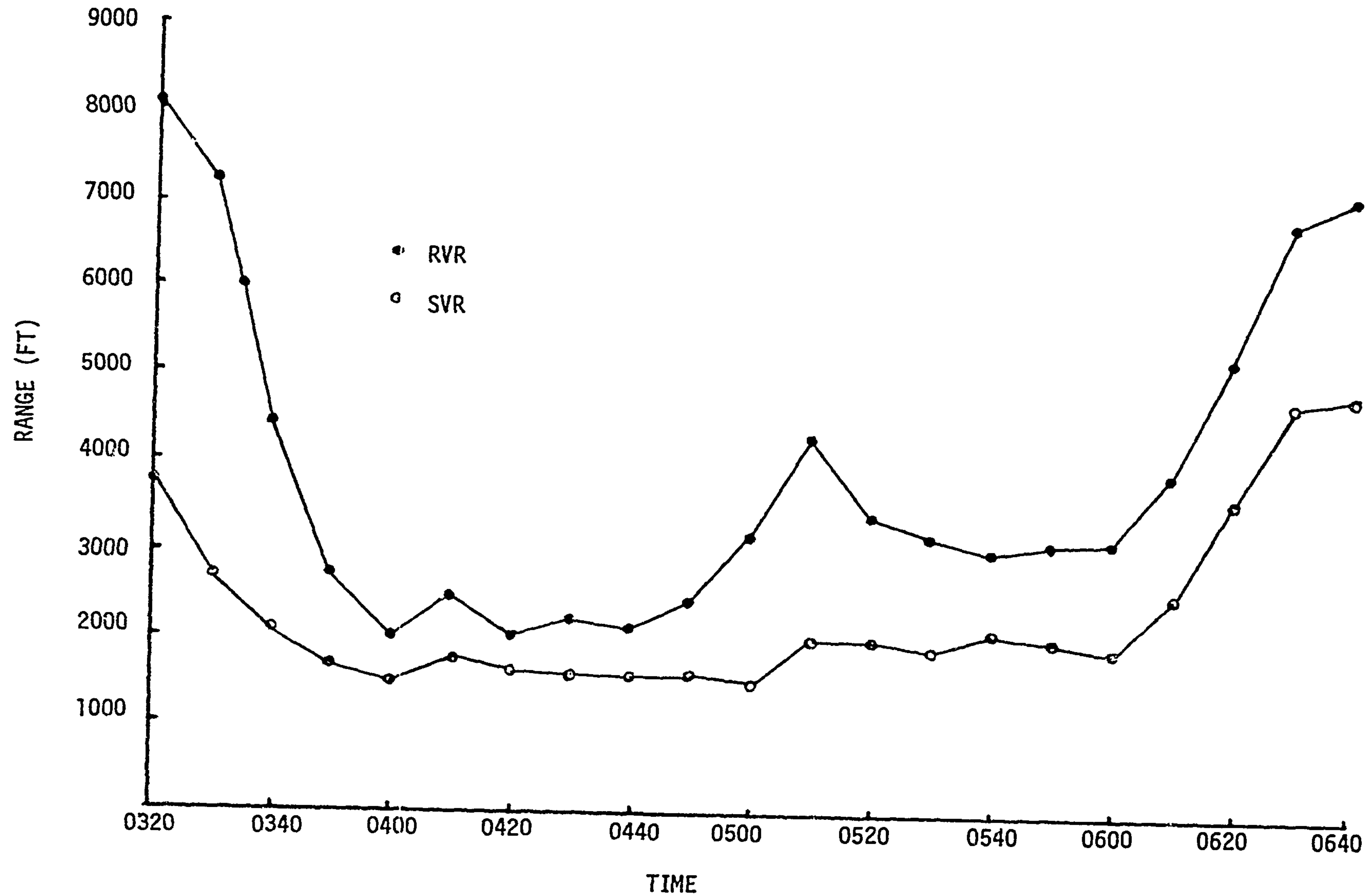


FIGURE 12

VISUAL RANGE COMPARISON (Cont)

FOG OF 25 JANUARY 1975, CONTINUED

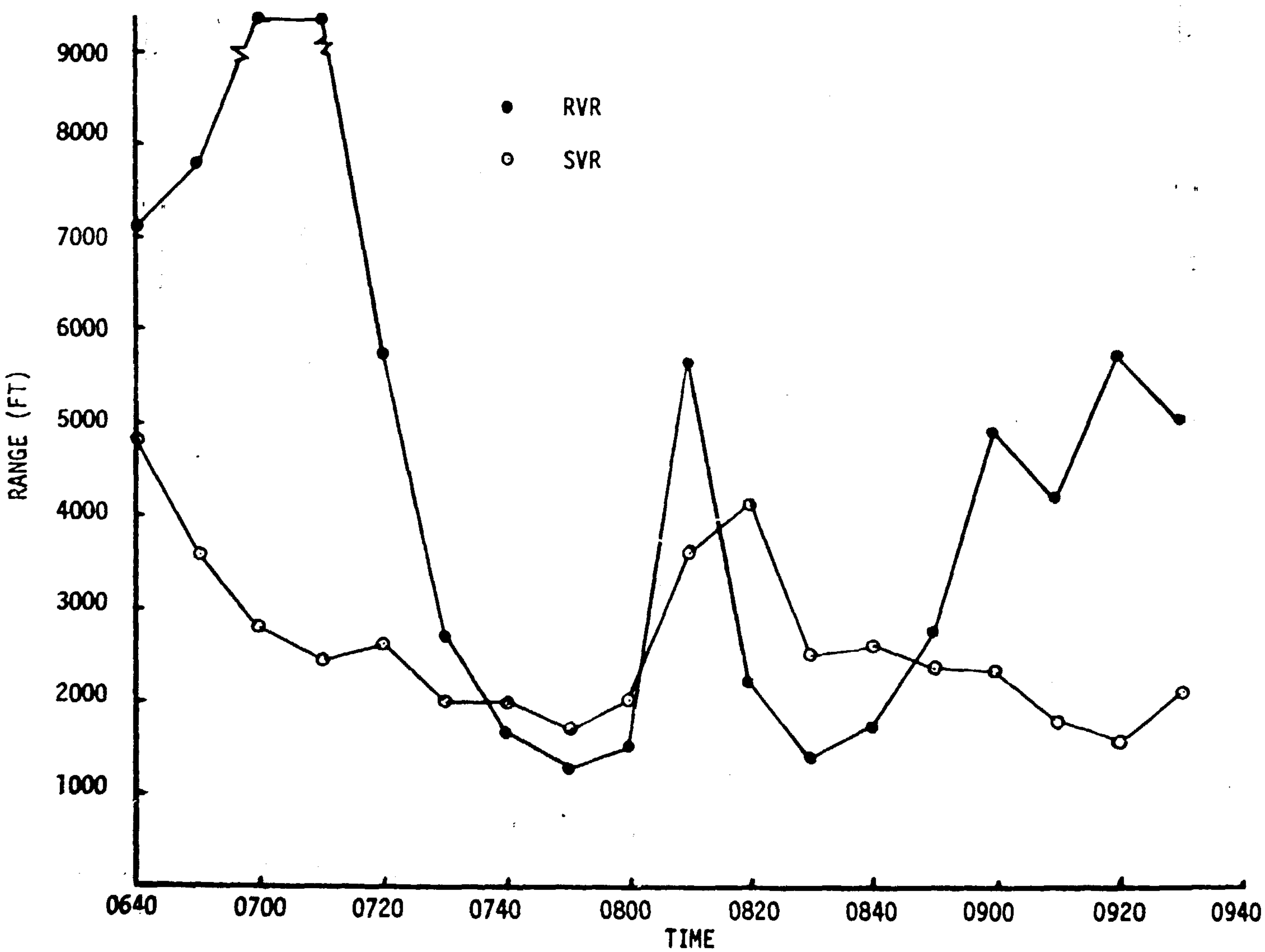


FIGURE 13

VISUAL RANGE DIFFERENCE COMPARISON

FOG OF 25 JANUARY 1975

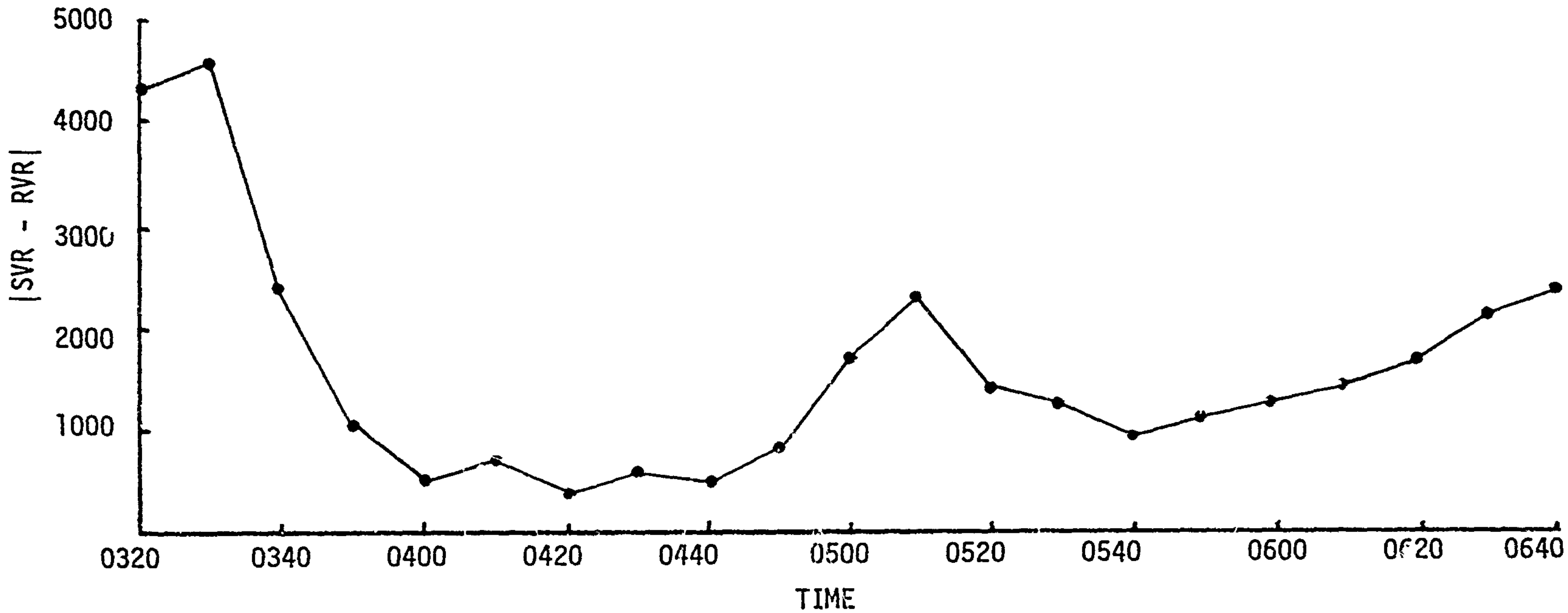


FIGURE 14

VISUAL RANGE DIFFERENCE COMPARISON (Cont)

FOG OF 25 JANUARY 1975

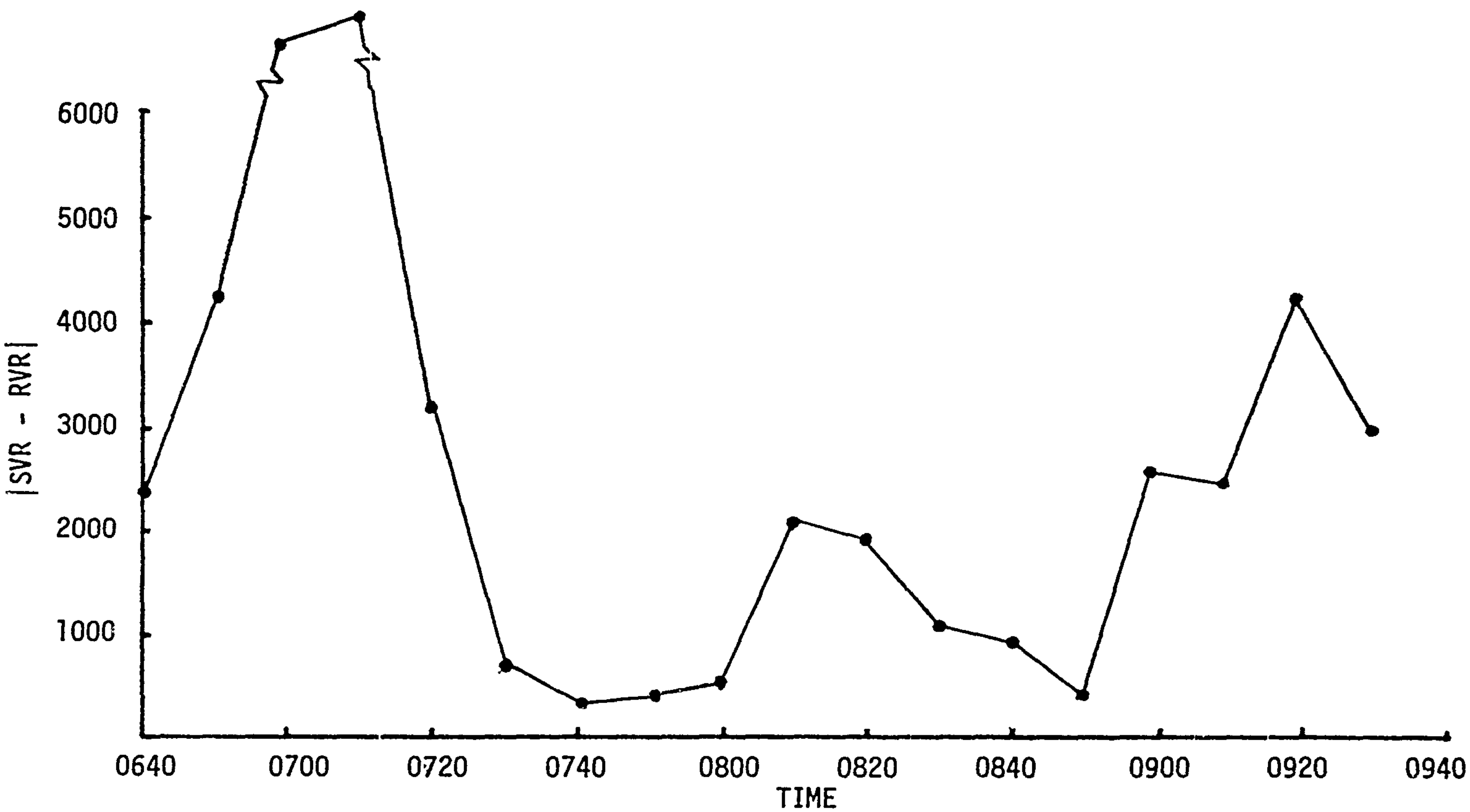


FIGURE 15

7. SYSTEM RELIABILITY

As stated earlier, the system became fully operational in the fall of 1974. During this period, most of the individual components have functioned very well. However, there has been one major problem; the system has been disabled twice due to electrical storms. The storms have caused large current surges in the shielding of the cable connecting the SVR tower with the minicomputer. This has had the effect of destroying optical isolaters and drivers at both ends of the cable. On one occasion, the lightning seemed to come down the tower into the A/D box at the base of the tower.

The forward scatter meters, luminance meters, and minicomputers have all functioned extremely well. The minicomputer has been operating continuously for three years without a problem. However, a minicomputer peripheral device, namely the magnetic cassette driver, did malfunction. The motor drive bearing burned out because of the continuous operation of the motor. A solution to this problem would be to program the computer to turn the motor on only when data is actually being recorded. This would require hardware changes on the Nova 1220. Another solution would be periodic maintenance of the motor, e.g., motor lubrication and replacement of parts if necessary. No problems occurred with the FSM's or the luminance meters. The illuminance meter did malfunction due to moisture penetration into the cell after being repaired for lightning damage. The meter has now been vented to eliminate this problem.

False turn-ons of the FSM's also occurred during the testing period. The system is designed to activate when one of the FSM's falls below 90% transmission; however, turn-ons were occurring when the true transmission was greater than 90%. After some investigation, the tower was found to be swaying in the wind when the turn-ons occured. The tower is designed so that its bottom is hinged to the base support, and this hinged junction did not fit tightly, thus permitting the tower to sway when particular wind conditions existed. The false turn-on problem was solved by inserting metal shims at the hinge junction, thus prohibiting tower movement.

Maintenance of the system has been minimal except for the problems enumerated above. Calibration of the FSM's and luminance meters were done before the tower was mounted to the base. After the tower is in its upright position, it is difficult to calibrate the meters; therefore, calibration or maintenance of the FSM optics and luminance meters requires that the tower be lowered to the ground. This is a time consuming and difficult task.

8. CONCLUSIONS AND RECOMMENDATIONS

The results of tests on the SVR/ALCH system indicates that the system can yield meaningful data. However, insufficient data was obtained to provide definitive conclusions. Limited SVR tests under Category II conditions yielded estimates having average differences from the pilot reported values by, in one series 380 feet, and in another series 300 feet. The discrepancies between reported and estimated SVR are approximately 25% of the average reported SVR values.

ALCH observations have proven to be accurate when values of ALCH are 200 feet and below. Little testing has been completed at higher ALCH values under fog conditions. The average difference between the reported and estimated values of ALCH on the complete 25 September test was 40 feet. This difference represents 17% of the average reported ALCH value for that test series. The 24 February test has an average difference between reported and predicted values of 35 feet which is 24% of the average pilot reported ALCH.

Verification of the estimated SVR values was very difficult. The distance/reporting technique may account for some of the discrepancies between the reported and estimated SVR values.

In the experiment conducted under the conditions of test the pilot stated the number of visible runway edge lights. This methodology is acceptable under low Category II conditions when the pilot sees one to five edge lights; however, under less dense situations, he may see 10 to 20 or even more lights. The pilot, when at 100 feet altitude under these stressful conditions, cannot be expected to accurately determine the number of lights visible.

The system demonstrated high reliability but did prove to be susceptible to lightning. New system installations should provide further protection of the system from lightning damage. Lightning damage can be reduced or possibly eliminated by installing transient suppressors before the electronic circuits at both ends of the cable, enclosing the signal and power cables in a metal conduit instead of its present grounding at the tower and at both ends of the cable. If the grounding procedures do not curtail the current surges, then the transient suppressors will act as fuzes to protect the system. The suppressors have switch opening times in microseconds as compared to milliseconds for fuzes.

Calibration of the 100 foot forward scatter meter (FSM) required lowering the entire tower. New system installation should include easier calibration. The calibration difficulty could be greatly reduced by redesigning the tower to allow the FSM to be raised and lowered on a track on the side of the tower.

The methodology utilized to determine the top of a fog layer requires modification to improve the reporting of the top of a fog layer. A technique utilizing a laser ceilometer could greatly simplify and increase the accuracy of ALCH estimates in the 150 feet to 400 foot range in addition to having the potential of achieving the desirable goals of determining both top of the fog and the cloud height.

APPENDIX A

SVR/ALCH ALGORITHM

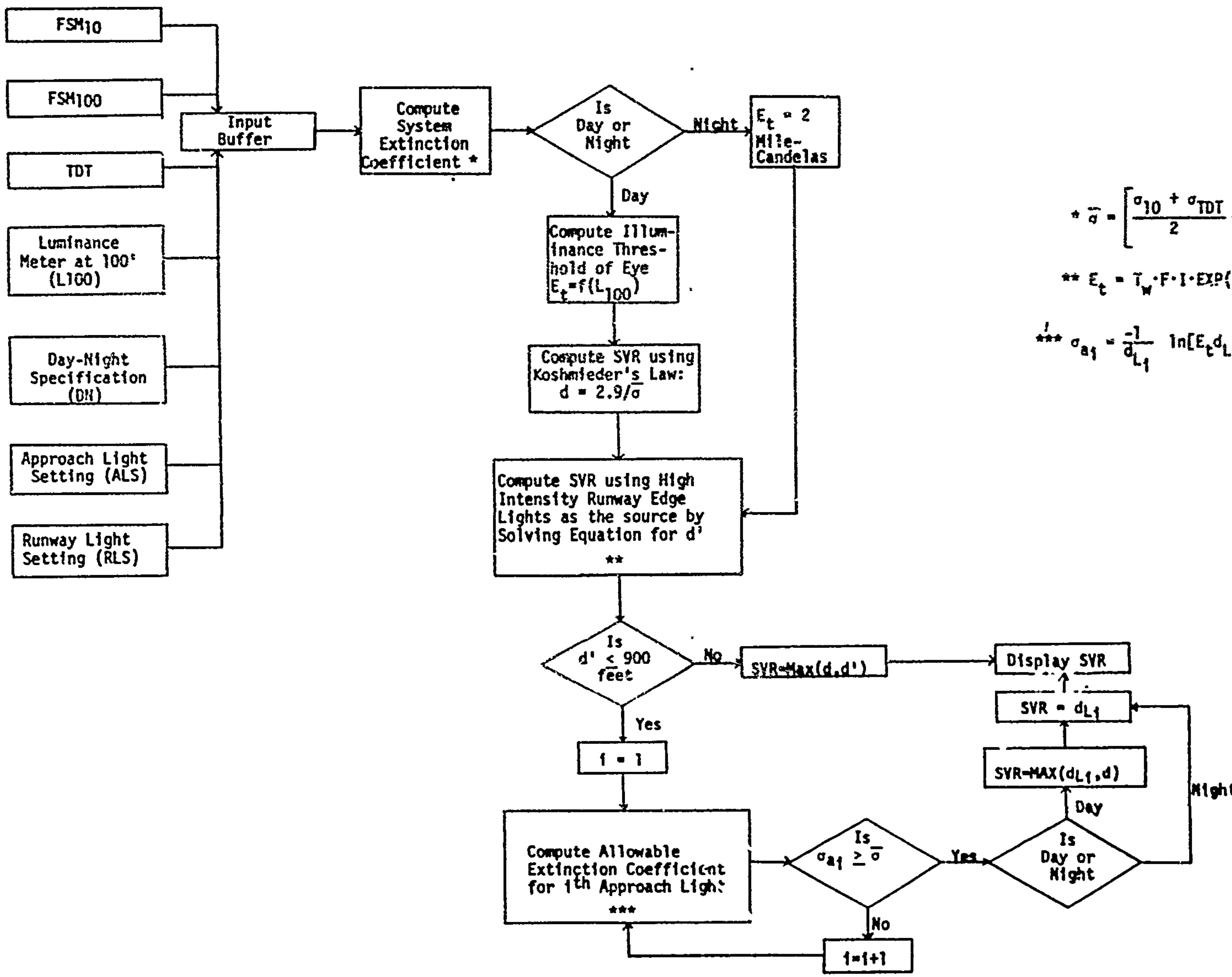
Presented in this section is a description of the SVR/ALCH algorithm. Found below are definitions of terms which will be used throughout the SVR/ALCH description. Flow diagrams are presented in Figures A-1 and A-2 for the SVR and ALCH algorithms respectively. They should prove useful in the understanding of the algorithms.

TDT	- The touchdown transmissometer; reads % transmission over 250' baseline.
FSM_{10}	- The forward scatter meter placed a +10' on the SVR/ALCH tower; reads % transmission over 250' baseline.
FSM_{100}	- The forward scatter meter placed at 100' on the SVR/ALCH tower; reads % transmission over 250' baseline.
TOF	- The height above ground level which is the upper boundary of the fog.
DN	- Day or night specification.
ILLM	- The illuminance on the ground level illuminance meter placed next to the SVR/ALCH tower.
L_{50}	- Reading of the 50' luminance meter in footlamberts.
L_{100}	- Reading of the 100' luminance meter in footlamberts.
ALS	- Approach light setting; corresponds to a particular approach light setting.
XLONG	- Airport longitude.
XLAT	- Airport latitude.
DAY	- Day of the year expressed as a Julian date.
HR	- Hour based on 24-hour clock.
MIN	- Minute of the hour.

Slant Visual Range (SVR)

The computer system computes SVR for (1) day case or (2) night case. The day case is chosen if the day-night photocell reads over

SVR FLOW DIAGRAM



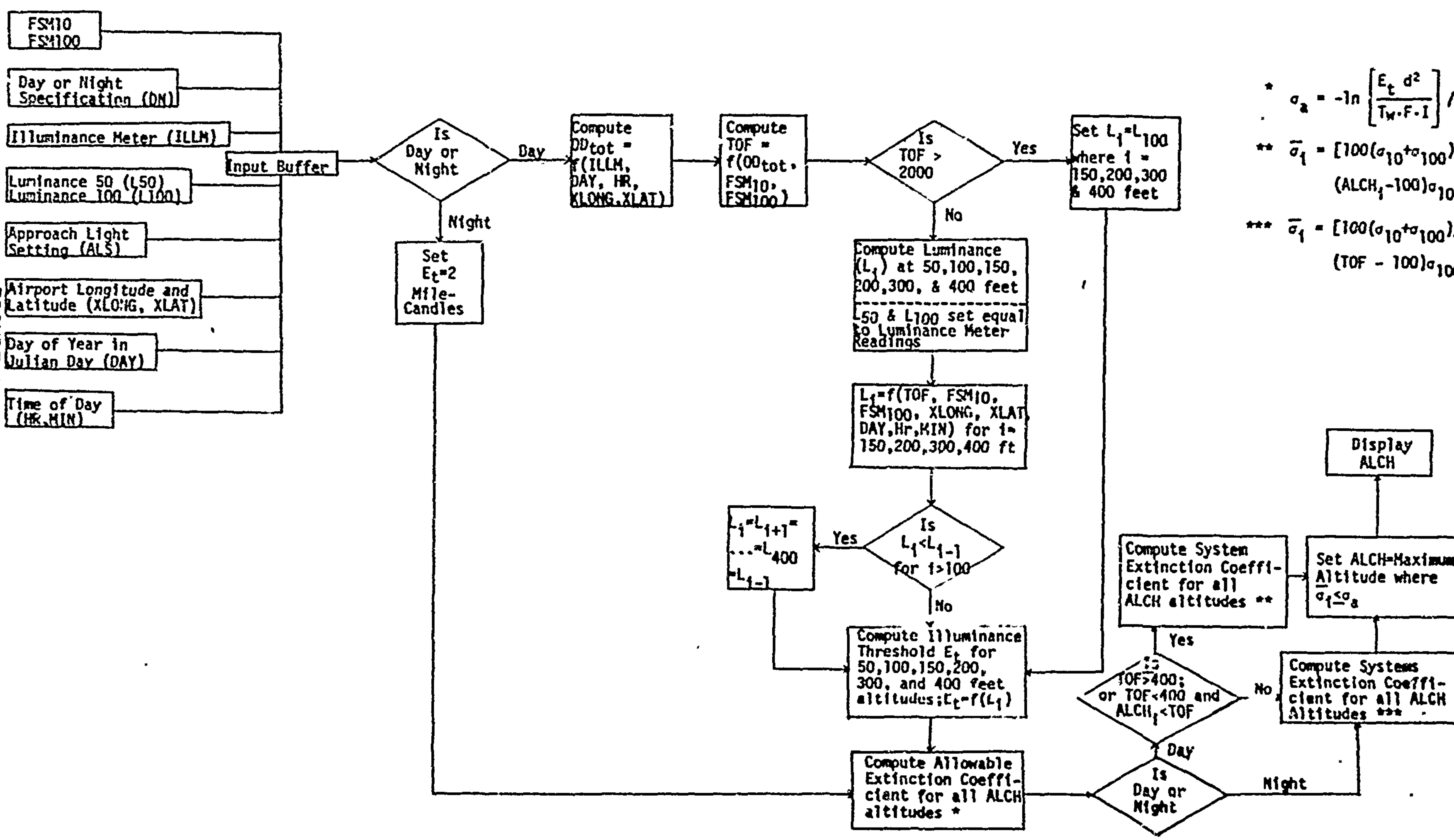
$$* \ \bar{\sigma} = \left[\frac{\sigma_{10} + \sigma_{TDT}}{2} + \sigma_{100}\right]/2$$

$$** \ E_t = T_W \cdot F \cdot I \cdot EXP(-\bar{\sigma} \cdot d')/d'^2$$

$$*** \ \sigma_{a_i} = \frac{-1}{d_{L_i}} \ \ln[E_t d_{L_i}/(T_W I)]$$

FIGURE A1

ALCH FLOW DIAGRAM



$$* \quad \sigma_a = -\ln\left[\frac{E_t\, d^2}{T_w \cdot F \cdot I}\right]/d$$

$$** \quad \overline{\sigma}_i = [100(\sigma_{10}+\sigma_{100})/2 + (ALCH_i - 100)\sigma_{100}]/ALCH_i$$

$$*** \quad \overline{\sigma}_i = [100(\sigma_{10}+\sigma_{100})/2 + (TOF - 100)\sigma_{100}]/ALCH_i$$

FIGURE A2

80 footcandles and the night case is chosen if the day-night photocell reads equal or under 80 footcandles.

SVR Night Case

The computer calculates SVR based on the high intensity runway edge lights as the source. Then if SVR is less than or equal to 900 feet (where the approach lights start), it then calculates SVR based on the intensity of the approach lights.

High Intensity Runway Edge Lights

The intensity of the runway edge lights are 20,000, 4,000, and 800 candelas for the respective runway edge light settings 5, 4, and 3. The illuminance threshold (E_t) necessary to see a high intensity runway edge light is fixed in the computer as $E_t = 7.174 \times 10^{-8}$ footcandles for the night case. Equation (A-1) is solved numerically for SVR, and then SVR is truncated to hundreds of feet.

$$E_t = T_w \cdot F \cdot I \cdot EXP(-\bar{\sigma} \cdot SVR)/SVR^2 \qquad \text{(A-1)}$$

where $E_t = 7.174 \times 10^{-8}$ footcandelas
where I = 20,000 candelas
where F = factor used to reduce the runway edge light intensity based on the light setting (see below).
where T_w = transmission of the wind screen set equal to 0.8.

Runway Edge Light Setting	F
5	1.0
4	.2
3	.04
2	.04
1	.04

Approach Lights

The approach light bars which are geometrically possible to see from the 100-foot altitude, counting from threshold, are the 1st, 2nd, 3rd, 4th, and 5th which have an approximate slant range respectively of 900, 800, 700, 600, and 500 feet. The intensity of the approach light bar of interest is precalculated taking into account the aim direction of the lights, the position of the pilot, light setting, and the number of lights on the bar. The precalculated intensities were then entered into the computer as constants. The extinction coefficient ($\bar{\sigma}$) is derived in the following manner. The extinction coefficients at the SVR tower 10' level and touchdown transmissometers are averaged to yield an average extinction coefficient at ground level. This value is then averaged with the SVR tower 100' extinction coefficient. This is shown in the following equation:

$$\bar{\sigma} = \left[\frac{\sigma_{10} + \sigma_{TDT}}{2} + \sigma_{100}\right] /2 \qquad \text{(A-2)}$$

An allowable extinction coefficient (σ_a) is then computed as in equation (A-3). The extinction coefficient ($\bar{\sigma}$) is then compared to σ_a. If σ_a is less than $\bar{\sigma}$ for the first approach light bar, then the process is continued until $\sigma_a \geq \bar{\sigma}$ or until the first five light bars are checked. Once σ_a is found to be greater than $\bar{\sigma}$, the light bar which corresponds to the last computed σ_a is used to set SVR = d. If $\sigma_a < \bar{\sigma}$ for the first five lights, then SVR is equal to 0.

SVR Day Case

As in the night case, SVR is calculated based on the high intensity runway edge lights or approach lights. Similarly, the high intensity runway edge lights are the source for SVR > 900 feet and the approach lights are the source for SVR $\leq$ 900. The $\bar{\sigma}$ is calculated as in the SVR night case.

Runway Edge Lights

The luminance meter reading at 100 feet is used as the adaptation level of the pilot. The illuminance threshold E_t is then computed as a function of the 100' luminance meter (equation(A-4)). This function is derived from Blackwell's 1946 data. Given E_t and $\bar{\sigma}$ (estimated effective extinction coefficient from 0 to 100 feet), SVR can be computed by numerically solving equation (A-1).

Approach Lights

The reading of the 100-foot luminance meter is used in calculating illuminance thresholds (E_t) as described in equation (A-4). By using the distance between observer and first approach light bar, equation (A-3) can be solved for the extinction coefficient σ_a. The estimated coefficient $\bar{\sigma}$ is then compared to σ_a. If $\bar{\sigma} > \sigma_a$, then σ_a is calculated for the 2nd light bar. The process is continued until the first five light bars are exhausted, in which SVR = 0; or until $\bar{\sigma} \leq \sigma_a$, in which case SVR is set equal to the distance between pilot and the light bar considered. It should be noted that the intensity of the approach lights is calculated in the same mannner as the Night Case Approach Lights.

Once an SVR is calculated from either of the above procedures, the following check is then performed. Koschmieder's principle is then applied to find the range, d, at which 5.5 percent transmission exists for the estimated extinction coefficient $\bar{\sigma}$. Equation (A-5) illustrates the Koschmieder effect. If d is greater than the SVR just calculated, then SVR is redefined as d.

$$\sigma_a = -\ln(E_t \cdot d^2/(T_W \cdot F \cdot I))/d \qquad \text{(A-3)}$$

where

Approach Light	I Candelas	d
1	104436	905
2	100552	806
3	93196	707
4	76780	608
5	39552	509

$$E_t = 10^y \tag{A-4}$$

where $y = a_0 + a_1 x + a_2 x^2 + a_3 x^3$

where $x = \log_{10}(T_w \cdot L_{100})$ and

$a_0 = -7.6104$

$a_1 = .640386$

$a_2 = .06497$

$a_3 = -.0031469$

L_{100} = reading of the 100' luminance meter (footlamberts)

$$d = 2.9/\bar{\sigma} \tag{A-5}$$

where $\bar{\sigma}$ is defined as before.

Approach Light Contact Height (ALCH)

ALCH is divided into (1) night case and (2) day case. The algorithm is based on the approach lights acting as the source.

ALCH Night Case

The approach light contact height calculations for night conditions are initiated when the day/night switch is set to night.

In the SVR algorithm described previously, a maximum uniform extinction coefficient was determined that would just allow detection of the approach light bars of interest. The ALCH is obtained in a similar manner.

Contained in the calculation of the maximum allowable extinction coefficient are the approach bars sighted at each ALCH prediction point. The bars sighted at each ALCH point are shown in Table A-1.

TABLE A-1

Bars Sighted at ALCH Points

ALCH PREDICTION ALTITUDE	BARS SIGHTED
50	Assumed bars are located at 400' through 800' from touchdown
100	1-5
150	10-14
200	18-22
300	26-30
400	26-30

The maximum allowable extinction coefficient is calculated as follows:

$$\sigma_{ai} = -\ln[E_t \cdot d^2/(F \cdot T_w \cdot I)]/d \qquad \text{(A-6)}$$

where

ALCH Prediction Alt. (ft)	I (Candelas)	d(ft)
50	104436	602
100	104436	905
150	100644	1011
200	103764	1216
300	107104	2418
400	98144	4418

$F = 1$; for setting ALS = 5.

$F = .2$; for setting ALS = 4.

$F = .04$; for setting ALS = 3, 2, 1.

E_t = threshold illuminance = 7.174×10^{-8} footcandles.

RVR calculations use F = .04 for light settings 1, 2, and 3. Therefore, SVR and ALCH calculations will be treated in a similar manner.

Included in the calculations is the transmittance of the aircraft windscreen. The transmittance has tentatively been set at .8.

To determine ALCH at night, the predicted extinction coefficient from ALCH/SVR system ($\bar{\sigma}_i$) (see equation (A-7)) for each ALCH prediction point is compared to the maximum allowable extinction coefficient (see equation (A-3)). If the system predicted extinction coefficient for the 400-foot ALCH prediction point ($\bar{\sigma}_{400}$) is less than or equal to the maximum allowable for detection, an ALCH of 400 is selected. If $\bar{\sigma}_{400}$ is greater than the maximum allowable for the 400-foot level, the $\bar{\sigma}_{300}$ is compared to the maximum allowable for detection at that prediction point. If $\bar{\sigma}_{300}$ is less than or equal to the maximum allowable, a 300-foot ALCH is selected. If $\bar{\sigma}_{300}$ is greater than the maximum allowable, the process continues until an ALCH point extinction coefficient is less than that allowable. If the $\bar{\sigma}_i$ is never less than any of the maximum allowable extinction coefficients, an ALCH of zero is selected.

$$\bar{\sigma}_i = [100(\sigma_{10} + \sigma_{100})/2 + (\text{ALCH} - 100)\ \sigma_{100}]/\text{ALCH}. \qquad \text{(A-7)}$$

where $\sigma_{10} = -\ln(\text{FSM}_{10}/100)/250$

$\sigma_{100} = -\ln(\text{FSM}_{100}/100)/250.$

ALCH Day Case

Predicting ALCH is dependent on (a) the average extinction coefficients corresponding to the different ALCH altitudes and (b) the luminances at 50, 100, 150, 200, 300 and 400 feet. The computing algorithms for extinction coefficients are presented below.

Before proceeding, let TOF be defined as the altitude of the upper boundary of the fog layer; and OD_{TOT} as the total optical depth of the fog plus the normal atmosphere where optical depth is the extinction coefficient times altitude.

OD_{tot} is computed from the illumination meter reading, geographical location of airport, time and day of year, and a series of theoretically developed equations which predict $\log_{10}$ (ILLUMINATION ON GROUND)" as a function of sun cosine zenith angle (ZEN). Cosine sun zenith angle (ZEN) is computed as described in Appendix B. The "$\log_{10}$ (ILLUMINATION ON GROUND)" , E_i, is computed as follows:

$$E_i = a_{i0} + a_{i1}ZEN + a_{i2}ZEN^2 + a_{i3}ZEN^3 \qquad \text{(A-8)}$$

where i = 1 through 12 corresponds to the following optical depths respectively. OD_i = .25, .5, .75, 1.25, 1.75, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, and

$a_{1,0}$ = 2.68698	$a_{1,1}$ = 3.39983	$a_{1,2}$ = -3.14184	$a_{1,3}$ = 1.09677
$a_{2,0}$ = 2.45	$a_{2,1}$ = 4.34046	$a_{2,2}$ = -4.63367	$a_{2,3}$ = 1.91278
$a_{3,0}$ = 2.43981	$a_{3,1}$ = 4.15897	$a_{3,2}$ = -4.23874	$a_{3,}$ 1.69816
$a_{4,0}$ = 2.41016	$a_{4,1}$ = 4.03138	$a_{4,2}$ = -3.92628	$a_{4,3}$ 1.52789
$a_{5,0}$ = 2.39688	$a_{5,1}$ = 3.90485	$a_{5,2}$ = -3.72877	$a_{5,3}$ = 1.4659
$a_{6,0}$ = 2.39038	$a_{6,1}$ = 3.87422	$a_{6,2}$ = -3.68874	$a_{6,3}$ = 1.46305
$a_{7,0}$ = 2.32642	$a_{7,1}$ = 3.97298	$a_{7,2}$ = -3.89357	$a_{7,3}$ = 1.61391
$a_{8,0}$ = 2.30233	$a_{8,1}$ = 3.86911	$a_{8,2}$ = -3.69217	$a_{8,3}$ = 1.51199
$a_{9,0}$ = 2.21909	$a_{9,1}$ = 4.24344	$a_{9,2}$ = -4.48806	$a_{9,3}$ = 2.01232
$a_{10,1}$ = 2.21828	$a_{10,1}$ = 3.98626	$a_{10,2}$ = -3.96259	$a_{10,3}$ = 1.7058
$a_{11,0}$ = 2.18715	$a_{11,1}$ = 4.03844	$a_{11,2}$ = -4.07868	$a_{11,3}$ = 1.77203
$a_{12,0}$ = 2.15972	$a_{12,1}$ = 4.04080	$a_{12,2}$ = -4.04283	$a_{12,3}$ = 1.73031

The illumination meter reading is used in conjunction with the E_i equations to compute OD_{tot} as follows. A comparison is made between $\log_{10}$ (ILLM) and E_i for cosine sun zenith angle (ZEN) such that the following condition is found:

$$E_{i-1} \leq \log_{10} \text{(ILLM)} \leq E_i \qquad \text{(A-9)}$$

where ILLM is the illumination meter reading in footlamberts.

A linear interpolation is then performed to compute OD_{tot} as follows.

$$OD_{tot} = OD_{i-1} + (OD_i - OD_{i-1})(E_i - \log_{10} ILLM)/(E_i - E_{i-1}) \qquad (A-10)$$

The following inequality conditions are imposed to compute OD_{tot}:

If $\log_{10}(ILLM) > E_1$, then $OD_{tot} = OD_1$.
If $\log_{10}(ILLM) \leq E_{12}$, then $OD_{tot} = OD_{12}$.

Given OD_{tot}, the top of the fog (TOF) can now be computed.

$$TOF = (OD_{tot} - .3)/[(\sigma_{10} + \sigma_{100})/2] \qquad (A-11)$$

where σ_{10} and σ_{100} are the extinction coefficients at 10 and 100 feet and the .3 is the optical depth associated with a clear atmosphere.

By knowing TOF, the extinction coefficients that the system predicts can be found from one of the following equations for the conditions specified.

For TOF $\geq$ 400 feet or when TOF < 400 feet and $ALCH_i$ < TOF, the following equation is used.

$$\overline{\sigma}_i = [100(\sigma_{10} + \sigma_{100})/2 + (ALCH_i - 100)\sigma_{100}]/ALCH_i. \qquad (A-12)$$

For TOF < 400 feet and $ALCH_i \geq$ TOF, the following equation is used.

$$\overline{\sigma}_i = [100(\sigma_{10} + \sigma_{100})/2 + (TOF-100)\sigma_{100}]/ALCH_i. \qquad (A-13)$$

Calculating the luminances at the ALCH altitudes is done in the following manner. The luminances at 50 and 100 feet are set equal to the readings from the 50 and 100-foot luminance meters. For altitudes greater than 100 feet, a theoretical study was performed and equations formulated to predict luminances as a function of (1) the ratio of the amount of fog above the $ALCH_i$ point of interest to the total optical depth; (2) the total optical depth; (3) the cosine sun zenith angle; and (4) B+C the azimuth angle of the sun relative to the runway. (See appendix).

Before describing the computing algorithm using the above parameters, it should be noted that the algorithm is now always used in computing the luminances, L_i. The following restrictions apply.

If TOF > 2,000 feet, then

$$L_{100} = L_{150} = L_{200} = L_{300} = L_{400}. \tag{A-14}$$

When using the computing algorithm and the following condition occurred

$$\begin{aligned} &L_i < L_{i-1} \text{ for } i > 100, \text{ then} \\ &L_i = L_{i+1} = \cdots = L_{400} = L_{i-1} \end{aligned} \tag{A-15}$$

The computing algorithm is as follows. The ratio (R_i) of the amount of fog above the $ALCH_i$ point of interest to the total optical depth (OD_{tot}) is defined as

$$R_i = \frac{OD_{tot} - [\sigma_{10} + \sigma_{100})/2]ALCH_i}{OD_{tot}} \tag{A-16}$$

where $[(\sigma_{10} + \sigma_{100})/2]$ $ALCH_i$ is the optical depth from the ground to the ALCH point of interest.

The second and third parameters, namely OD_{tot} and ZEN, are defined as before. The sun azimuth angle (AZIM) relative to the runway is computed as explained in Appendix B. By knowing R_i, OD_{tot}, ZEN and AZIM, the luminances for the various $ALCH_i$ altitudes (L_i) can be computed from

$$L_i = (11600)(3.14159)(.01)10^Q, \tag{A-17}$$

where

$$Q = f(R_i, OD_{tot}, \text{ZEN}, \text{AZIM}).$$

A detailed description is given in Appendix C.

With the luminances at the ALCH points determined, the illuminance thresholds for these altitudes are calculated as follows:

$$E_{ti} = 10^{P} \tag{A-18}$$

where $P = a_0 + a_1 w + a_2 w^2 + a_3 w^3$

and $w = \log_{10}(.8\ L_i)$

$a_0 = -7.6104$

$a_1 = .640386$

$a_2 = .06497$

$a_3 = -.0031469.$

With E_{t50}, E_{t100}, E_{t150}, E_{t200}, E_{t300}, E_{t400} known, equation (A-6) can be solved for σ_{a400}. If $\sigma_{a400} < \overline{\sigma}_{400}$, equation (A-6) is resolved for σ_{a300} using E_{t300} for the 300-foot ALCH altitude. The process is continued until $\sigma_{ai} \geq \overline{\sigma}_i$. ALCH is then set to the altitude that corresponds to the i^{th} subscript. If $\sigma_{a50} < \overline{\sigma}_{50}$, then ALCH = 0. The approach light bars for the different ALCH altitudes, which are considered in solving for σ_a are given in the night case ALCH description.

APPENDIX B

Calculations of Sun Azimuth and Cosine Zenith Angles

Included in this appendix are the calculations of the cosine of the sun zenith angle and the sun azimuth angle relative to the runway to which the pilot is approaching. The cosine sun zenith angle is calculated as a function of julian day of the year, time of day, longitude and latitude of airport, and time zone standard meridian. The computing equations are B-1, B-2, B-3, B-4, B-5, and B-6, as they are defined below. In computing the azimuth angle (AZIM) of the sun relative to the runway, the additional equations, B-7, B-8, B-9, B-10, B-11, and B-12, are needed.

$80 \geq \text{DAY} > 266$

$$\sigma = 23.381 \sin (.016884 (\text{DAY} - 79.797)) \qquad \text{(B-1)}$$

$\text{DAY} < 80$ or $\text{DAY} \geq 266$

$$\sigma = 23.643 \sin (.016863 (\text{DAY} - 80.042)) \qquad \text{(B-2)}$$

where DAY = Julian day of the year, i.e., December 31 is DAY = 365.

XLONG = Longitude of the airport

XLAT = Latitude of airport

STMER = Standard meridian for time zone which airport is located in; 75° = Eastern; 90° = Central; 105° = Mountain; 120° = Pacific.

RUNAZ = Azimuth of runway relative to magnetic north.

XMAGD = Magnetic declination angle of airport location, i.e., XMAGD = 10° for NAFEC airport.

HR = Hour of day.

MIN = Minute of hour.

$$\text{Define } T = \text{HR} + \text{MIN}/60 \qquad \text{(B-3)}$$

$$H = 15T - \text{XLONG} + \text{STMER} + 180 \qquad \text{(B-4)}$$

$$\text{ZEN} = \text{Sin (XLAT)} \sin \sigma + \cos \text{(XLAT)} \cos \sigma \cos H \qquad \text{(B-5)}$$

If $(\text{ZEN} \leq .19)$ $\text{ZEN} = \phi$, where ZEN is the cosine zenith angle. (B-6)

$$\text{Define COSA} = \sin (\sigma) - \sin \text{(XLAT) ZEN}/(\cos \text{(XLAT)} \sqrt{1-\text{ZEN}^2}\ ) \qquad \text{(B-7)}$$

$$A = \text{TAN}^{-1} \text{(SQRT(1-(COSA)(COSA))/COSA)} \qquad \text{(B-8)}$$

Re-define $A = A + 3.14159$ if $A < 0$. (B-9)

Re-define $A = 6.283185308 - A$ if $H > 360$. (B-10)

Define $AZIM = ABS(180A/3.14159 - RUNAZ + XMAGD)$. (B-11)

Re-define $AZIM = 360 - AZIM$ if $AZIM > 180$. (B-12)

APPENDIX C
Calculation of Adaptation Luminance

A series of six equations have been developed which compute "$\log_{10}$ (Luminance)" as a function of a linear combination of equal optical depth (OD_{tot}), zenith angle (ZEN), and the ratio (R_i) of the amount of fog above the $ALCH_i$ point of interest to the total optical depth. Five of the six equations are used for particular sun azimuth (azimuth in degrees) angles. These angles are 0°, 22.5°, 45°, 67.5°, and 90°. For an azimuth angle between 90-180, a single equation is used to computer "$\log_{10}$ (Luminance)" as a function of OD_{tot}, ZEN and R_i. For the sun zenith angle between 0 and 90 degrees, an interpolation scheme is employed as follows:

Define $X_1 = OD_{tot}$
$X_2 = AZIM$
$X_3 = ZEN$
$X_4 = R_i$

For $0 \leq X_2 \leq 22.5$

$$Q = LOGL1 + (X_2/22.5)(LOGL2-LOGL1)$$

where $LOGL1 = b_0 + b_1X_1 + b_2X_3 + b_4X_1X_1 + b_5X_3X_3 + b_6X_4X_4 +$

$$b_{10}X_1X_1X_3 + b_{11}X_1X_1X_4 + b_{12}X_1X_3X_3 + b_{14}X_1X_4X_4 + b_{15}X_3X_4X_4.$$

and

$b_0 = 1.0637$
$b_1 = -.20607$
$b_2 = 4.9381$
$b_3 = -1.878$
$b_4 = .012823$
$b_5 = -4.4423$
$b_6 = .83688$
$b_{10} = -.026671$
$b_{11} = .012919$
$b_{12} = .35712$
$b_{14} = -.068116$
$b_{15} = -.30055$

and

$$LOGL2 = c_0 + c_2X_3 + c_3X_4 + c_4X_1X_1 + c_5X_3X_3 + c_6X_4X_4 + c_7X_1X_3 + c_8X_1X_4 + c_{10}X_1X_1X_3 + c_{11}X_1X_1X_4 + c_{12}X_1X_3X_3 + c_{13}X_3X_3X_4 + c_{14}X_1X_4X_4 + c_{15}X_3X_4X_4.$$

where:

c_0 = .13073
c_2 = 2.9977
c_3 = 1.3422
c_4 = .0012119
c_5 = -3.698
c_6 = -1.2053
c_7 = .61004
c_8 = -.60886
c_{10} = -.05885
c_{11} = .03191
c_{12} = .012359
c_{13} = 1.9586
c_{14} = .24937
c_{15} = -1.155

For $22.5 < X_2 \leq 45$

$Q = LOGL2 + [(X_2 - 22.5)/22.5]\ (LOGL3 - LOGL2)$, where

$$LOGL3 = d_0 + d_1X_1 + d_2X_3 + d_3X_4 + d_4X_1X_1 + d_5X_3X_3 + d_6X_4X_4 + d_7X_1X_3 + d_8X_1X_4 + d_9X_3X_4 + d_{10}X_1X_1X_3 + d_{11}X_1X_1X_4 + d_{12}X_1X_3X_3 + d_{13}X_3X_3X_4 + d_{14}X_1X_4X_4 + d_{15}X_3X_4X_4$$

and

d_0 = .6245
d_1 = -.21369
d_2 = 3.0214
d_3 = -.22514
d_4 = .01975
d_5 = -3.2782
d_6 = -.39178
d_7 = .53322
d_8 = -.09688
d_9 = -.84711
d_{10} = -.04699
d_{11} = -.0028734
d_{12} = -.045416
d_{13} = 1.8694
d_{14} = .10416
d_{15} = -.29009

For $45 < X_2 \leq 67.5$

$Q = LOGL3 + [(X_2 - 45.)/22.5](LOGL4 - LOGL3)$

where $LOGL4 = f_0 + f_1X_1 + f_2X_3 + f_3X_4 + f_4X_1X_1 + f_5X_3X_3 + f_6X_4X_4 + f_7X_1X_3 + f_8X_1X_4 + f_9X_3X_4 + f_{10}X_1X_1X_3 + f_{11}X_1X_1X_4 + f_{12}X_1X_3X_3 + f_{13}X_3X_3X_4 + f_{14}X_1X_4X_4 + f_{15}X_3X_4X_4$.

and

$f_0 = .44868$
$f_1 = -.0667$
$f_2 = 1.305$
$f_3 = -.26963$
$f_4 = .0050875$
$f_5 = -1.1793$
$f_6 = -.4435$
$f_7 = .53118$
$f_8 = -.16366$
$f_9 = 1.0958$
$f_{10} = -.035825$
$f_{11} = .0045092$
$f_{12} = -.19438$
$f_{13} = -.27981$
$f_{14} = .093607$
$f_{15} = -.16048$

For $67.5 < X_2 \leq 90$

$Q = LOGL4 + [(X_2 - 67.5)/22.5](LOGL5 - LOGL4)$, where

$LOGL\,5 = h_0 + h_1X_1 + h_2X_3 + h_3X_4 + h_4X_1X_1 + h_5X_3X_3 + h_6X_4X_4 + h_7X_1X_3 + h_8X_1X_4 + h_9X_3X_4 + h_{10}X_1X_1X_3 + h_{11}X_1X_1X_4 + h_{12}X_1X_3X_3 + h_{13}X_3X_3X_4 + h_{14}X_1X_4X_4 + h_{15}X_3X_4X_4$,

and

$h_0 = .28503$
$h_1 = -.027551$
$h_2 = 1.2812$
$h_3 = -.44225$
$h_4 = .0008598$
$h_5 = -.98270$

$h_6 = -.23204$
$h_7 = .39245$
$h_8 = -.059275$
$h_9 = 1.3184$
$h_{10} = -.020867$
$h_{11} = .00085485$
$h_{12} = -.19426$
$h_{13} = -.37369$
$h_{14} = .024833$
$h_{15} = -.28015$

For $90 < X_2 \leq 180$

$$Q = a_0 + a_1X_3 + a_2X_1 + a_3X_4 + a_4X_4 + a_6X_1X_3 + a_7X_4X_3 + a_8X_1X_1 + a_9X_4X_4 + a_{10}X_3X_3$$

where

$a_0 = .27586$
$a_1 = 1.68462$
$a_2 = .030888$
$a_3 = -.46743$
$a_4 = -.026355$
$a_6 = .092099$
$a_7 = .77954$
$a_8 = -.0052141$
$a_9 = -.18306$
$a_{10} = -1.4209$

Having defined Q, ($\log_{10}$(luminance)), the following quantity can now be calculated as

$$L_i = 10^Q(11600)(3.14159)(.01).$$

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